

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 209

A One-Year Statistical Comparison of the
Hough and OI Data Assimilation Systems

Joseph P. Gerrity, Jr.
Development Division

JANUARY 1980

This is an unreviewed manuscript, primarily
intended for informal exchange of information
among NMC staff members.

1.0 Introduction

This report addresses the question, "How much difference has the use of the optimum interpolation (OI) analysis system made in the meteorological performance of the NMC data assimilation system (i.e., the Final Cycle)?" We are able to present only a partial answer to the question, an answer based on a comparison of the fit of analysis and first-guess fields to Northern Hemisphere radiosonde observations.

In 1977, a routine procedure was instituted to evaluate the fit of the Final Cycle analysis and first guess fields to observations at several networks of radiosonde stations. At that time, the Final Cycle analysis system used the Hough function, spectral method. In September of 1978, the OI analysis system was implemented in the Final Cycle. The evaluation code, called SUMAC, has now been run for more than 2 years. We shall focus upon the comparison afforded by 22 months of data, Oct. 77-Aug. 78 and Oct. 78-Aug. 79, on two observation networks, North America (NA) and Northern Hemisphere (NH). For a description of the method used to compile these statistics, the reader is referred to Office Note No. 197 by Dey and Caporaso (1979).

The variables that have been studied are wind speed, geopotential height and temperature at the four pressure levels, 850, 500, 250, and 100 mbs. We will present the results in that order, and will close with a summarization and outlook.

2. Wind Speed

In figure 1, a compact presentation is given of the 11-month average performance of the Hough and OI systems with respect to wind speed. The analysis and first-guess bias values are negative except for the North America network first guess at 100 mb (+0.15 m/s). The bias is rather small for both methods reaching no more than 2 m/s at 250 mb.

The root-mean-square (rms) deviation of the analysis and first guess are quite similar for both Hough and OI methods. At the 850 and 500 mb pressure levels, the OI system shows somewhat larger values of the "Growth" parameter.†

If the rms statistic may be treated as a measure of the standard deviation of a normally distributed error field,* we observe the variance of the first guess field (a 12-hour forecast in effect) to be double that of the analysis field. This is true for both analysis techniques, and is a measure of the error growth rate attributable to the forecast model which was the same in both instances, viz., the 9-layer Global PE.

*It would be useful to modify the SUMAC verification code to print out the frequency distribution of deviations.

†The growth parameter is the difference between the rms of the guess and the analysis divided by the rms of the analysis.

It is notable that the lower tropospheric winds are more closely represented by the OI analysis than by the Hough analysis. However this improvement was achieved, perhaps through a more highly variable isotach pattern, it is clear that the forecast model was unable to retain this apparent edge.

In Figures 2a through 2d, the rms deviation from observations of both the analysis and first-guess fields are shown, month by month.

It may be noted that the rms deviation of the analysis and first guess is larger during the fall and winter months. This annual variation is greatest at 250 mb for the Hough first guess.

By and large, especially since two different years are involved, one is impressed with the similarity of the statistics for the Hough and OI methods. One notable difference appears in October and November. In spite of the near identity of the analysis statistics, the Hough 250 mb first guesses are notably worse than OI's. It's at least plausible that such an advantage might accrue to OI because of its analysis directly to the sigma coordinate. The statistics suggest that the period Oct-Nov provides the appropriate synoptic regime for use in tests of such a hypothesis.

3. Geopotential height

The 11-month average values of the bias and root-mean-square statistics for the Hough and OI, analyses and first guesses of geopotential height are presented in Figure 3. The Hough analysis system treats observed isobaric heights directly, whereas the OI system treats the thickness of the mandatory pressure layers. The Hough system incorporates a radiation correction of the observed heights at and above 100 mbs, a procedure which was omitted in the OI system and in the SUMAC code used in the statistical evaluation.

Consideration of the analysis bias shows that, over the 11 months, it remained less than 5 m except at 100 mbs. At 100 mbs, the Hough analysis is indicated to have a negative bias of 10 or 12 m. This extra bias may be attributed to the radiation correction and ought not to be regarded as a defect of the analysis system.

The radiation correction is substantial at middle and upper stratospheric levels. There is also a smaller systematic effect extending downward to the midtroposphere. We plan to introduce a more consistent treatment of the radiation correction into the OI system in the near future.*

*The SUMAC verification system should also incorporate a reasonable and consistent treatment of this radiation effect.

The bias of the first guess fields is negative for both methods except at 850 mbs where the Hough system has a positive bias. At every level, we note that the OI system has a positive bias in the analysis and a negative bias in the first guess. Thus the OI system displays a notable, systematic tendency to lower the isobaric heights field as it proceeds from analysis to guess. The behavior of the Hough system isn't as vertically consistent in this regard.

Turning attention to the rms statistic, it shows an increase at the higher atmospheric levels. The North American (NA) network shows OI to be slightly inferior to Hough at all levels.[†] Only in terms of the error growth does the OI system manifest superiority in the North America rms statistic. The Northern Hemisphere (NH) rms statistic shows the same sort of result except at 250 mbs where the OI system is clearly superior to the Hough system. For the Northern Hemisphere the error growth statistic shows no clear advantage to either system.

The month-by-month values of the bias statistic are shown in Figures 4a through 4d. At the three lower pressure levels, the analysis bias is rather uniform in value throughout the period. At the 100 mb level, however, we can observe an annual wave in the Hough bias, which is probably explained by the radiation correction procedure.

Inspection of the month-by-month first guess bias reveals rather peculiar behavior in the Hough and OI systems. At all levels the Hough first guess bias is positive or small negative during the winter and becomes small or large negative during the late summer. The OI system displays a smaller amplitude and opposite phase behavior; it tends to be large negative in winter. This opposition in phase argues against a diabatic physical mechanism of the prediction model being the cause of the observed behavior. The radiation correction, or its omission as the case may be, surely has a role, but one wonders if there is a dynamic cause at work. If the polar vortex's balance is treated in a systematically different fashion (Hough too intense, OI's not intense enough) one might expect the manifested behavior to result from the "geostrophic adjustment" process.

Turning attention to the rms statistic displayed in figures 5a through 5d, one finds little perplexing variability. Only at 100 mbs over the North American network do we find the analysis rms of the Hough and OI systems to significantly deviate from each other, but this difference is not manifested in the Northern Hemisphere network.

[†]We observe that OI's looser analysis fit appears to result in an undesired looseness of the fit of the first guess.

The closer fit of the Hough 100 mb North American analysis carries over to the production of a better guess. However, the 250 and 500 mb levels also show Hough's guess over North America to be superior even though the analysis fits of the two methods are very similar at these levels. It may be excessively speculative, but it is possible that the Hough's first guess superiority is due to the use of Eastern Pacific 250 mb bogus height data. In the same vein, the fact that Hough's superiority vanishes after April may be attributable to the introduction of Eastern Pacific Tiros-N data into the OI system at that time, thereby offsetting the absence of bogus data.

4. Temperature

We turn attention now to the mandatory level temperature. This parameter is not directly analyzed or predicted in the data assimilation system, its analyzed and predicted values are obtained by interpolation among the layer thickness temperatures. Again the 11-month average performance is shown in Figure 6.

The 850 mb bias statistic is remarkable; in every instance the guess has less bias than the analysis. The 850 mb rms statistic clearly shows the Hough system to outperform the OI system, but we must note that the growth statistic manifests the fact that the Hough system's analysis superiority is largely dissipated by the time the guess is generated.

At 500 mbs the OI system is superior to the Hough system by all measures except the rms of the analysis. At this level the Hough system's generous growth statistic succeeds in losing all the advantages provided by a smaller analysis rms.

The 250 mb level statistics are similar to the 500 mb level. OI again is superior to the Hough system on all counts barring the analysis bias statistic. Especially noteworthy however is the very large Hough guess bias statistic, almost 2°C too warm.

At the 100 mb level the Hough system turns the tables on OI by getting its error growth down to small values. While Hough is somewhat better than OI at 100 mbs, its advantage at 850 mbs was greater. These 11-month statistics point an accusatory finger at the OI 850 mb analysis system for temperature.

In Figures 7a through 7d, the month-by-month bias statistic is graphically displayed. In comparison with Hough, OI's 850 and 100 mb analyses are much too warm in the spring and summer. Over North America the OI first guess is too cold in winter and too warm in spring and summer. Only the summer warm bias is notably different from Hough on the Northern Hemisphere network.

It is disconcerting to note that the OI system's markedly warm, 850 mb temperature bias is not reflected in its geopotential height bias at 850 or 500 mbs. This suggests that the 700 and 1000 mb temperature biases must be compensatingly cold. However, there is an alternative explanation for this problem which would not require such compensation.

As noted earlier, the level temperature is derived from thickness temperatures which are reflective of the warmer virtual temperature. This is a reasonable explanation except that the effect should be present in the Hough system too, but it isn't. I could offer a further hypothesis to explain why the Hough analysis might not be subject to this effect, but I'm unable to explain the absence of the effect in the Hough guess temperature bias.

The OI system outperforms the Hough system at 500 and 250 mbs, especially in the 250 mb guess bias. At 100 mbs the Hough analysis bias is smaller than OI's, but the guess bias is a "mixed bag"--Hough is cold and OI warm, except when they are about the same.

The month-by-month march of the rms statistic is displayed in Figures 8a through 8d. Only at the 250 mb level does OI maintain a clear superiority over the Hough system. On the other hand, it is only at 850 mbs that the Hough system is routinely superior to the OI system.

5. Summary and Outlook

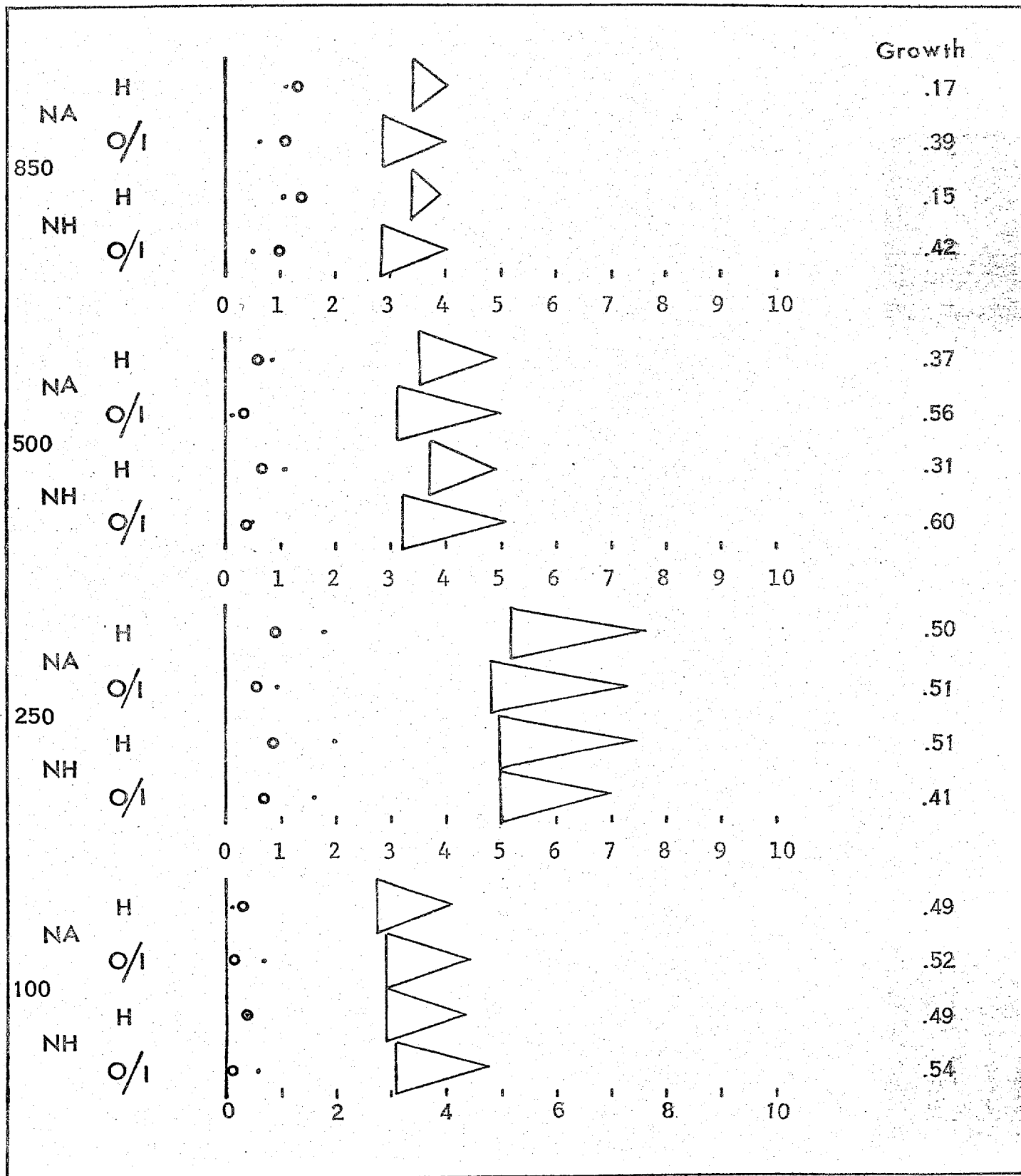
The principal motivation for implementing the OI system was the conviction that it provided a rational methodology for the analysis of satellite data. A comprehensive evaluation of the correctness of this conviction will require the conduct of carefully designed forecast-impact studies. The statistics discussed here are not sufficient to address this very important question. On the whole, however, this year-long comparison of the Hough and OI data assimilation systems does indicate that the OI system has had little impact on the performance of the Final Cycle in the data-dense parts of the Northern Hemisphere. There are some indications that OI was better (250 mb level), but there are compensating indications (850 mb level) that it has not performed so well as the Hough system did. We must also note that the OI system was continuously under development during the past year, therefore the OI statistics may very well be non-stationary. For this reason, it is planned to continue the program of systematic evaluation begun in 1977.

We anticipate the introduction of a new prediction model into the data assimilation system by next year. It will be a spectral model with 12 levels of resolution. We also plan to increase the vertical resolution of the analysis system. These are major changes which are fully expected to improve NMC's ability to assimilate satellite data within the context of current computer capabilities.

As we advance to this next step, it is worth noting the value of a systematic compilation of statistics for assessing performance. The automation of the statistical compilations in a variety of formats could facilitate their ultimate use.

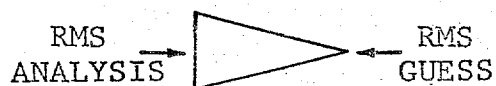
6. Acknowledgments

The materials used in this note were provided through the joint efforts of Drs. Stackpole and Dey. Mr. Krzenski drafted the figures and Mrs. Daigle typed the manuscript.

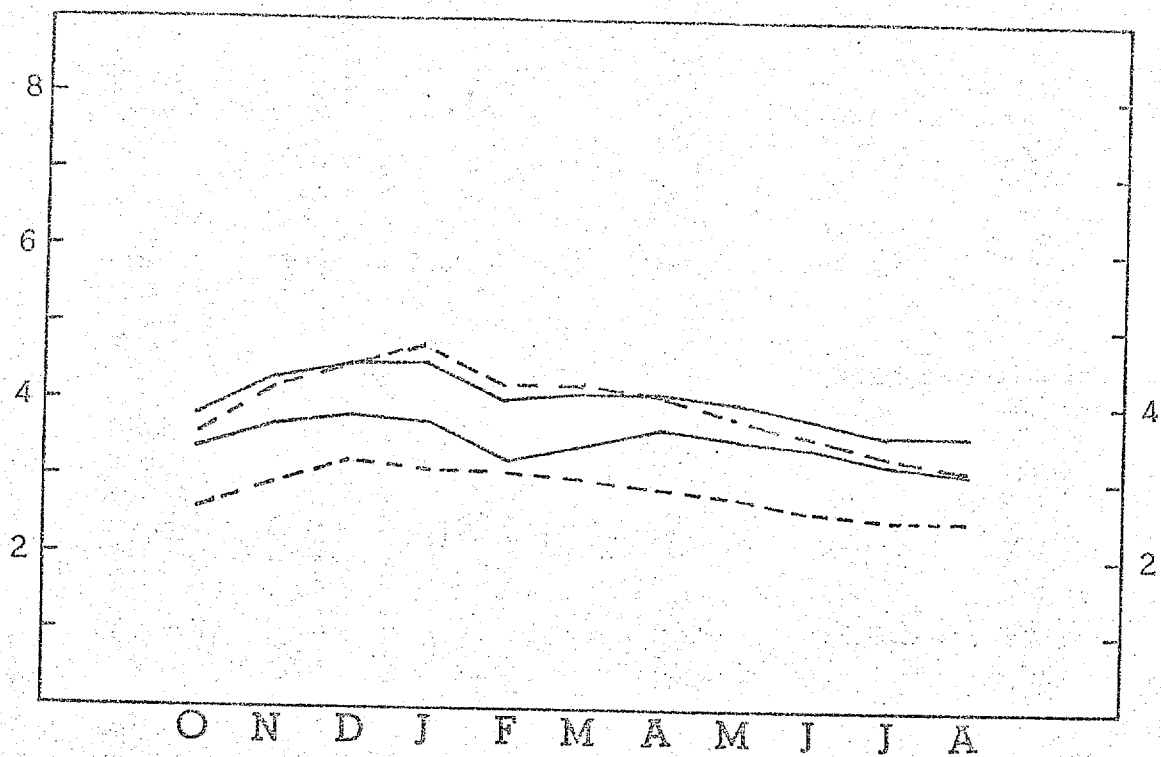


11 MONTH AVERAGE WIND SPEED DEVIATIONS M/S

○ ANALYSIS BIAS
• GUESS BIAS



$$\text{GROWTH} = \left(\frac{G - A}{A} \right)$$

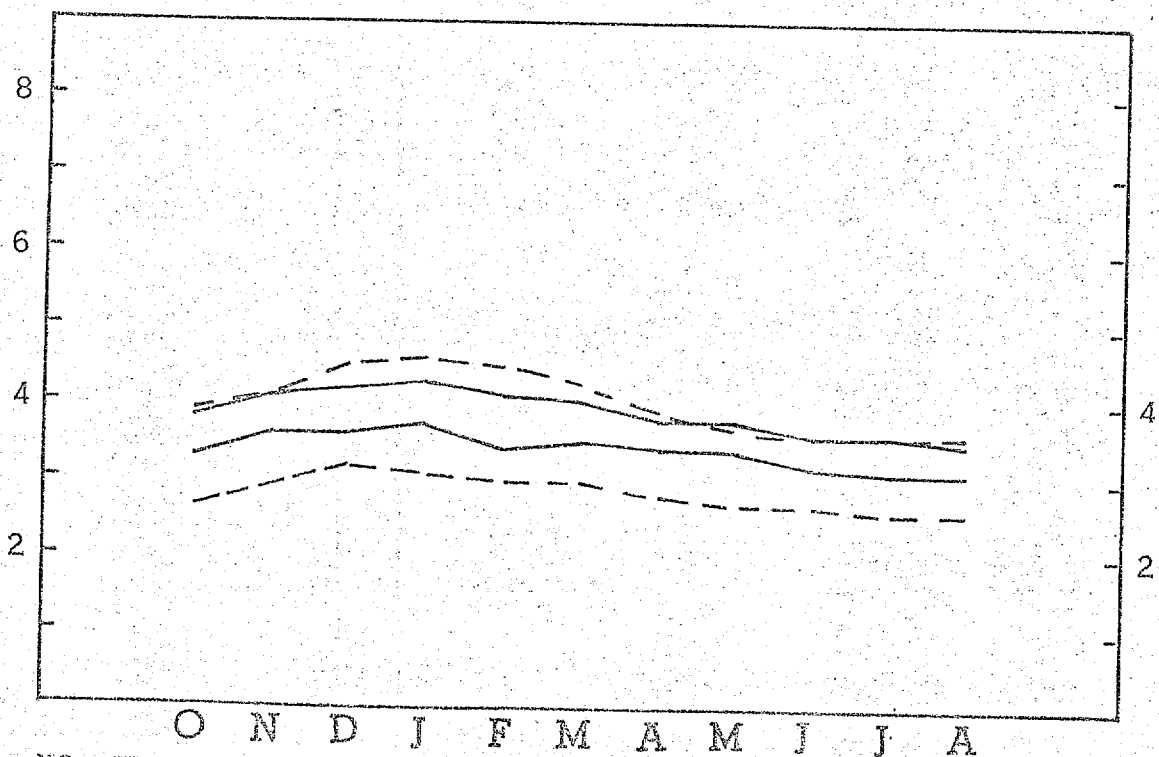


NO. AMERICA 110
850 MB

RMS WIND SPEED
ANL & FIRST GUESS

HOUGH

O/I



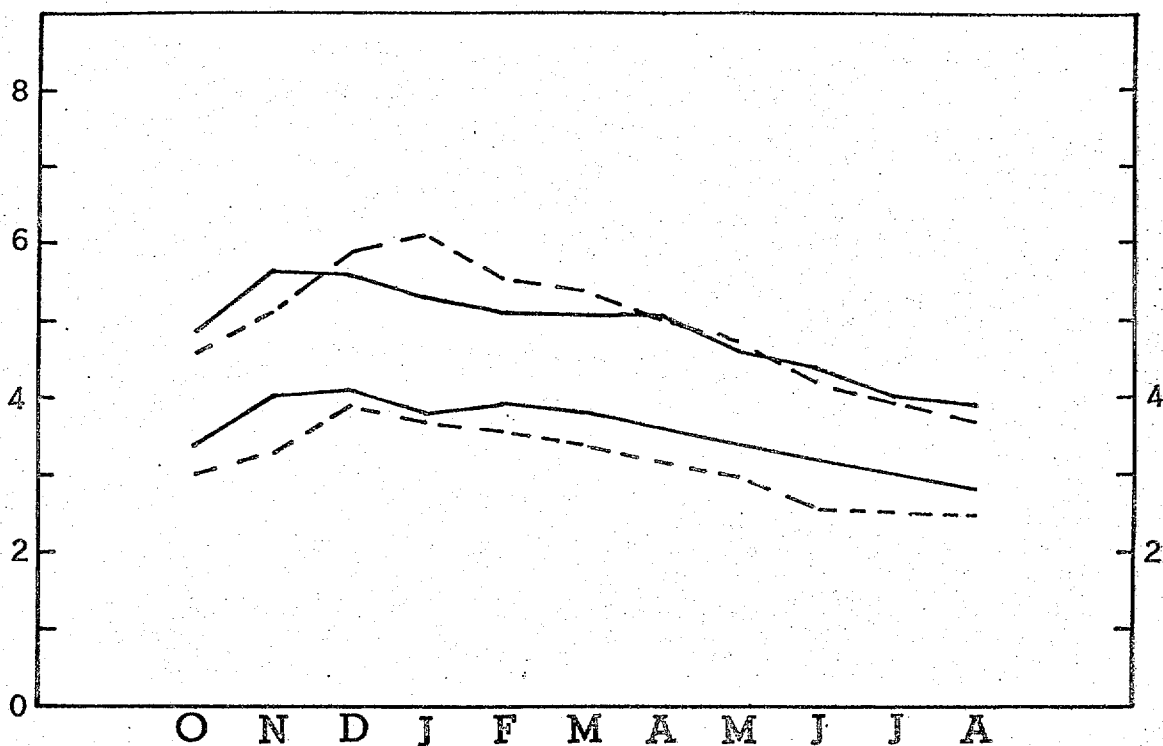
NO. HEMISPHERE 102
850 MB

RMS WIND SPEED
ANL & FIRST GUESS

HOUGH

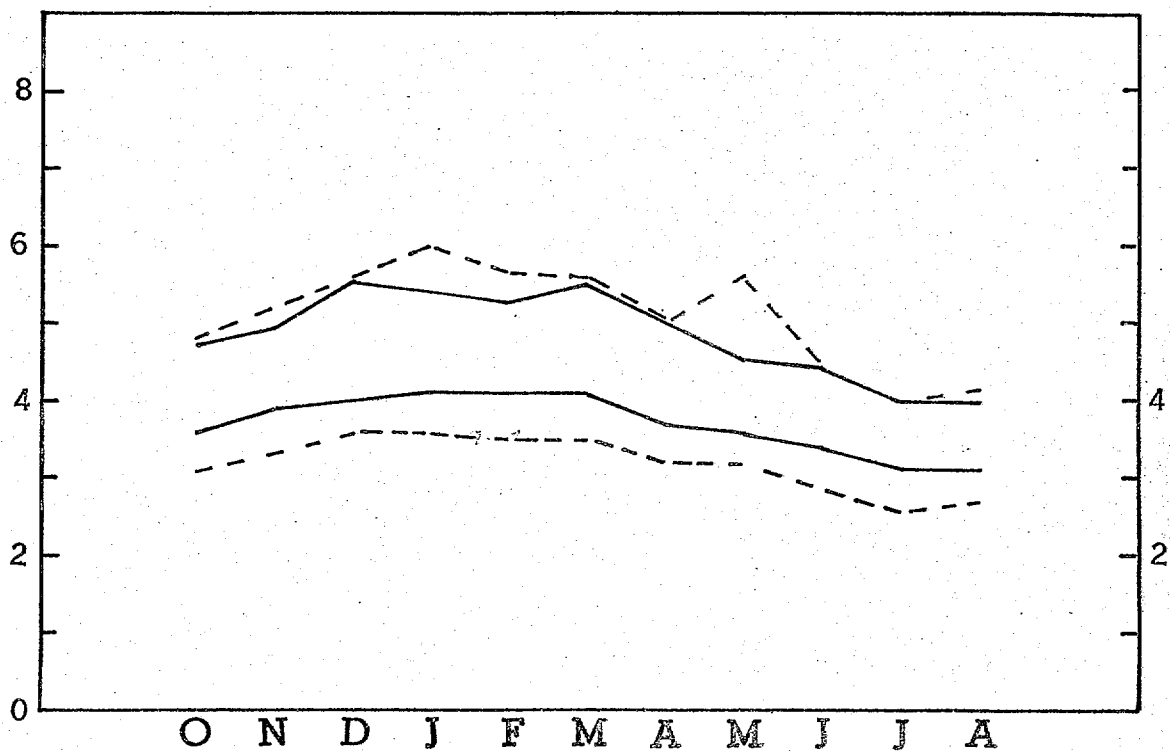
O/I

Fy 2a



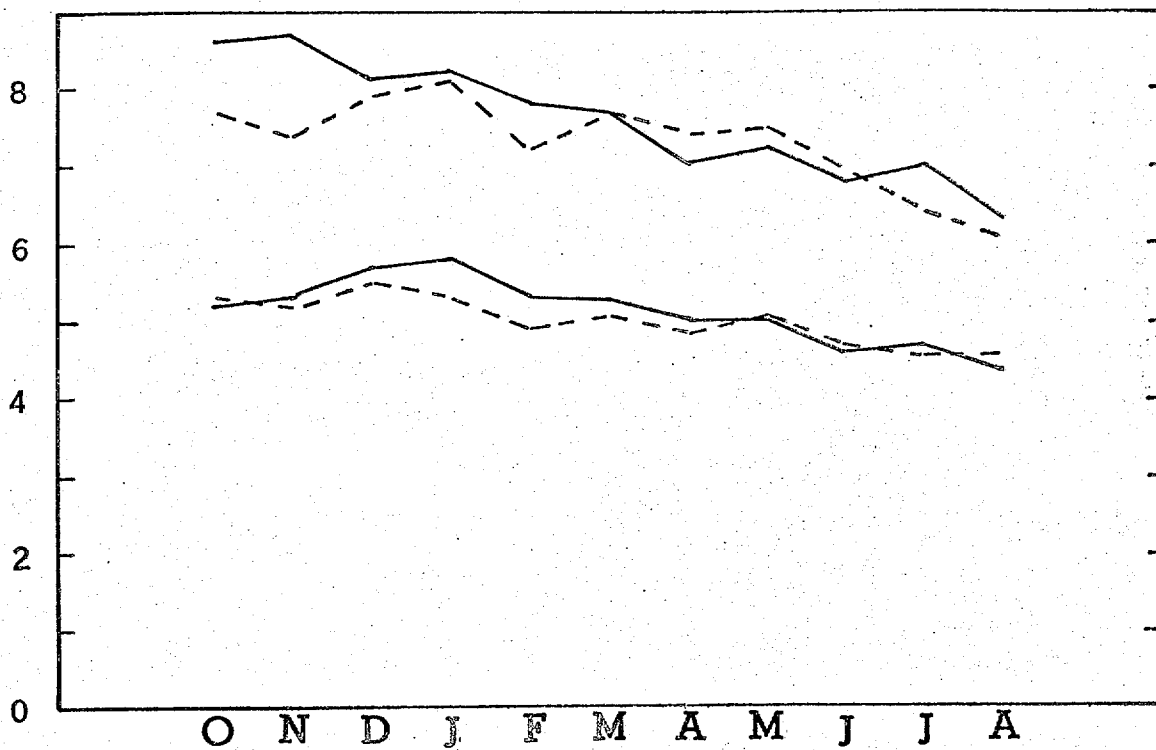
NO. AMERICA 110
 500 MB
 RMS WIND SPEED
 ANL & FIRST GUESS

HOUGH ———
 O/I - - - -



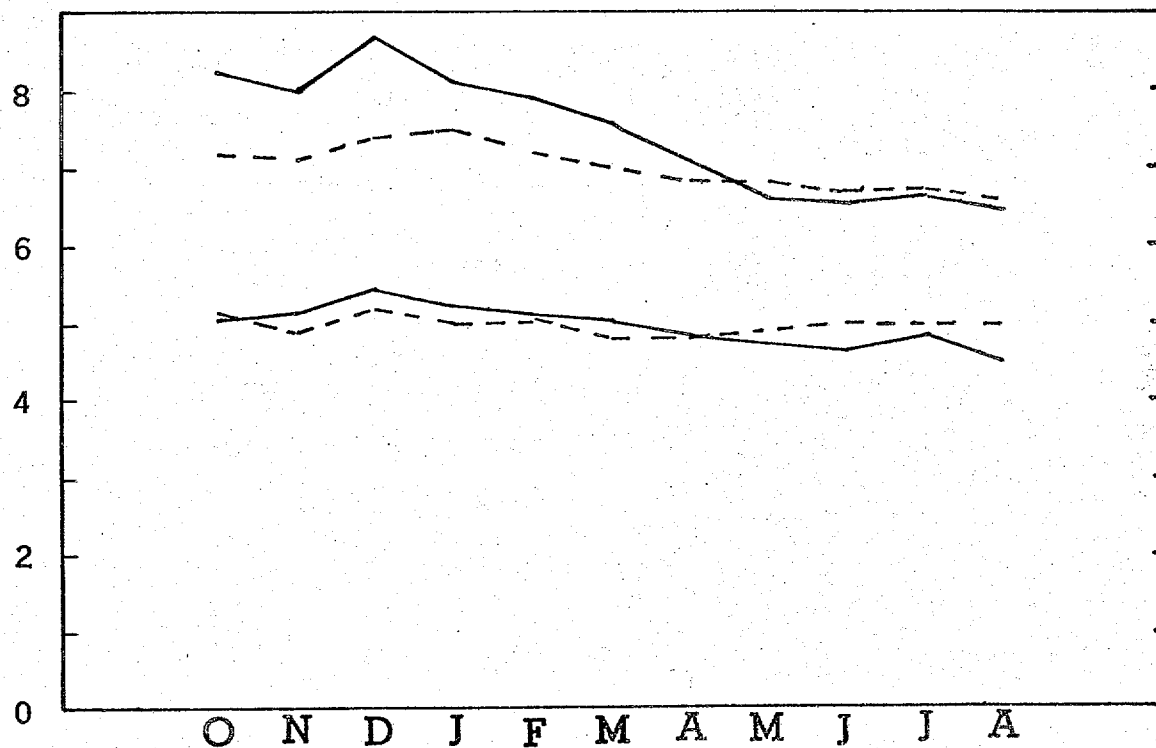
NO. HEMISPHERE 102
 500 MB
 RMS WIND SPEED
 ANL & FIRST GUESS

HOUGH ———
 O/I - - - -



NO. AMERICA 110
 250 MB
 RMS WIND SPEED
 ANL & FIRST GUESS

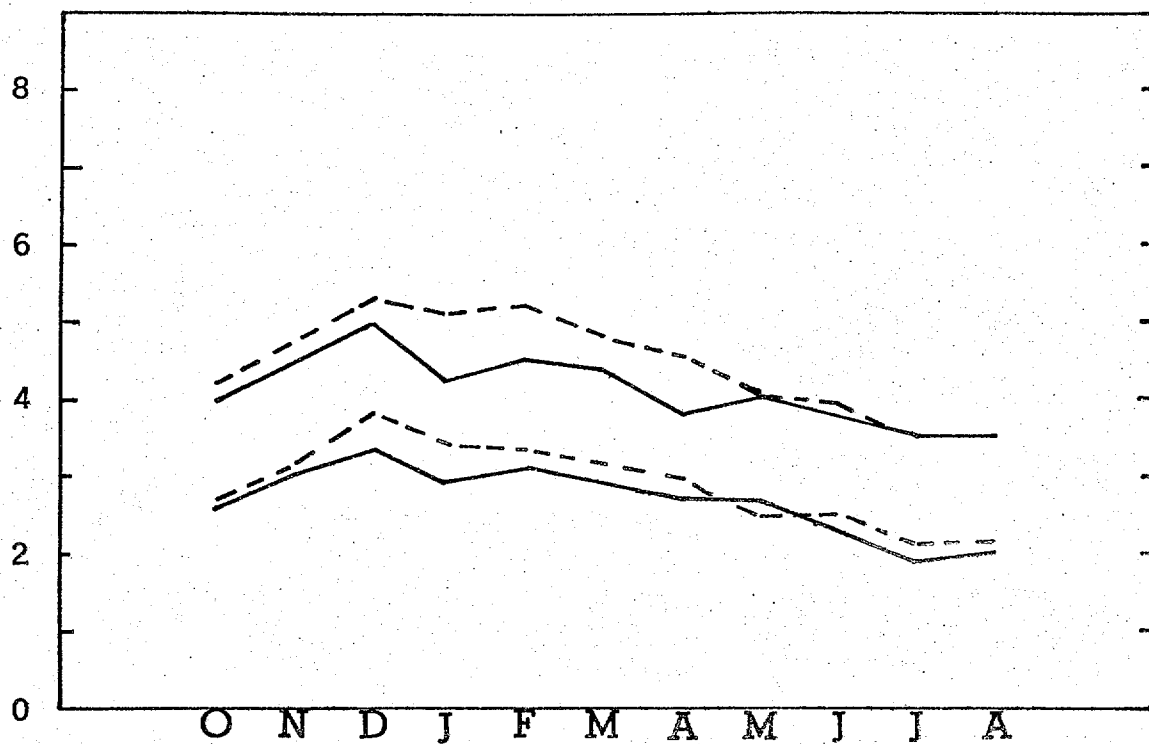
HOUGH ———
 O/I - - -



NO. HEMISPHERE 102
 250 MB
 RMS WIND SPEED
 ANL & FIRST GUESS

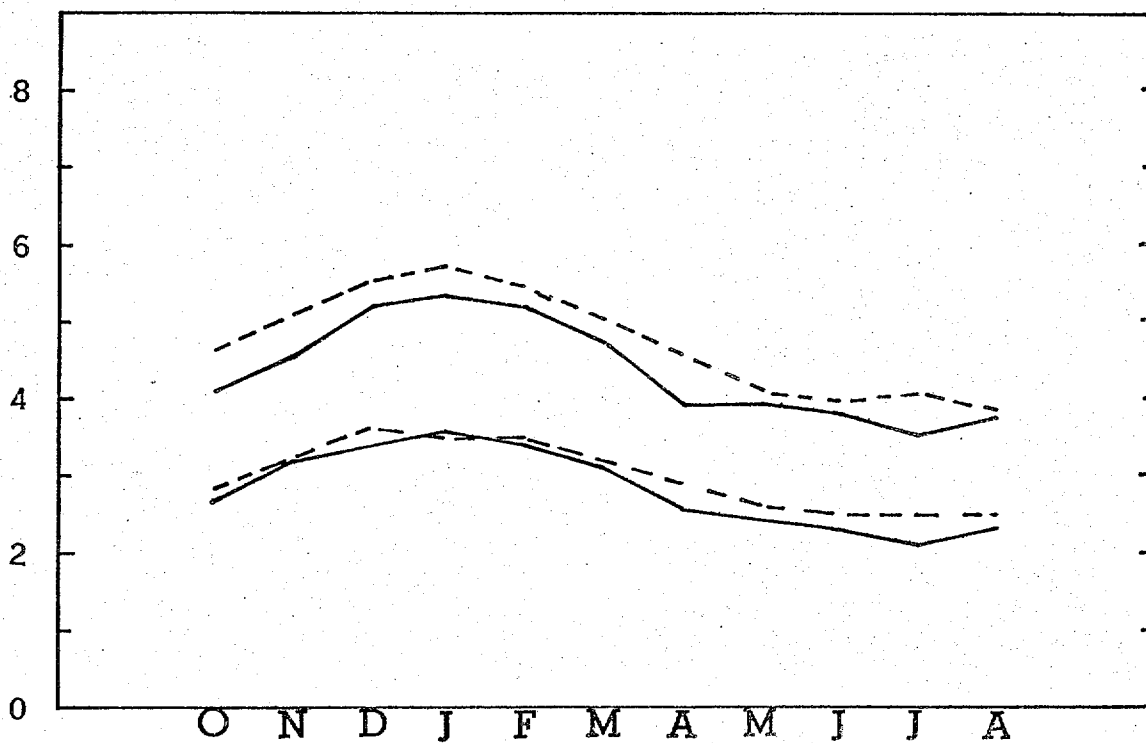
HOUGH ———
 O/I - - -

Fig 2c



NO. AMERICA 110
 100 MB RMS WIND SPEED
 ANL & FIRST GUESS

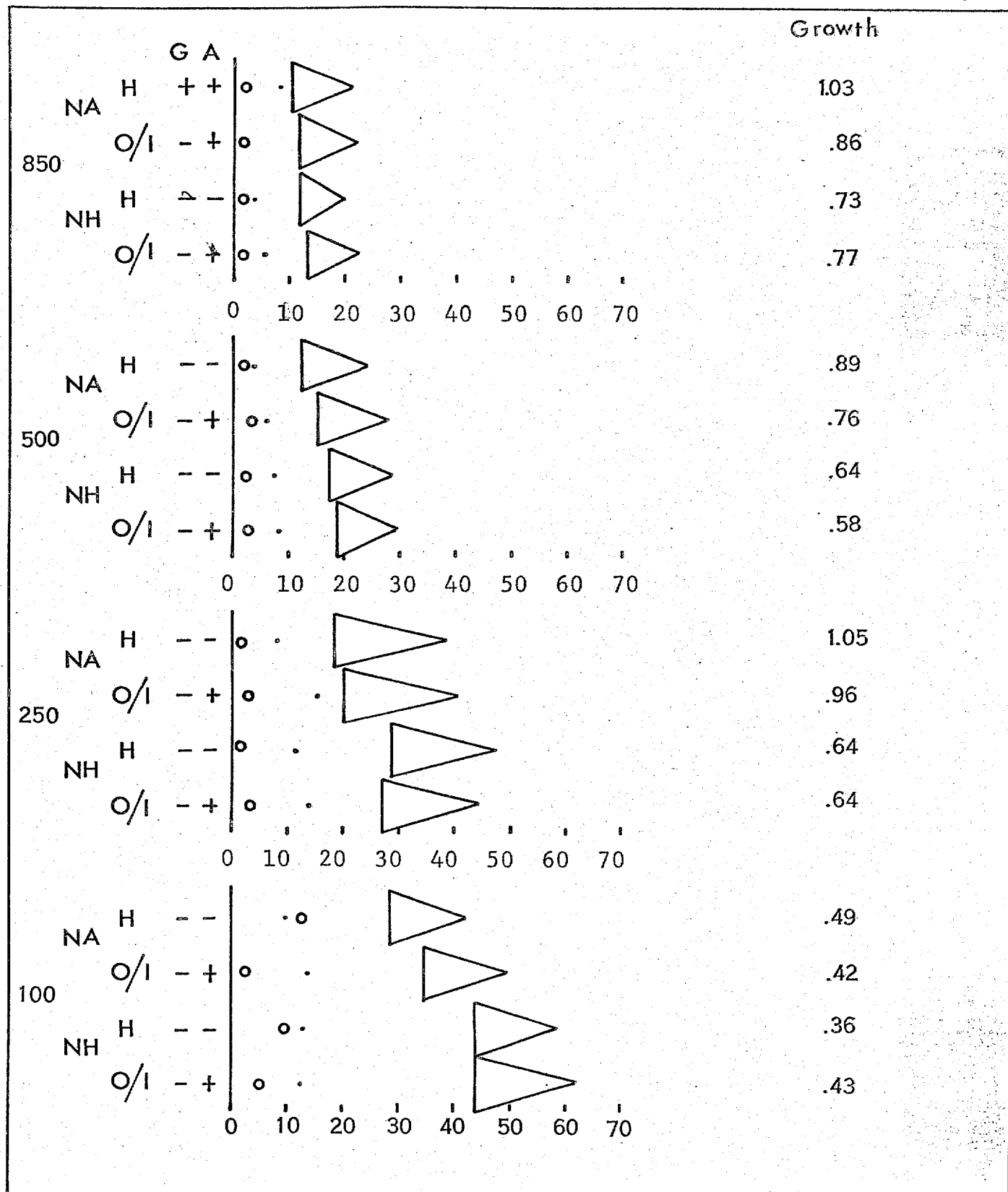
HOUGH ———
 O/I - - - -



NO. HEMISPHERE 102
 100 MB RMS WIND SPEED
 ANL & FIRST GUESS

HOUGH ———
 O/I - - - -

Lj2d.



11 month average height deviations m

o Analysis Bias

. Guess Bias



$$\text{GROWTH} \equiv \left(\frac{G - A}{A} \right)$$

Fig 3

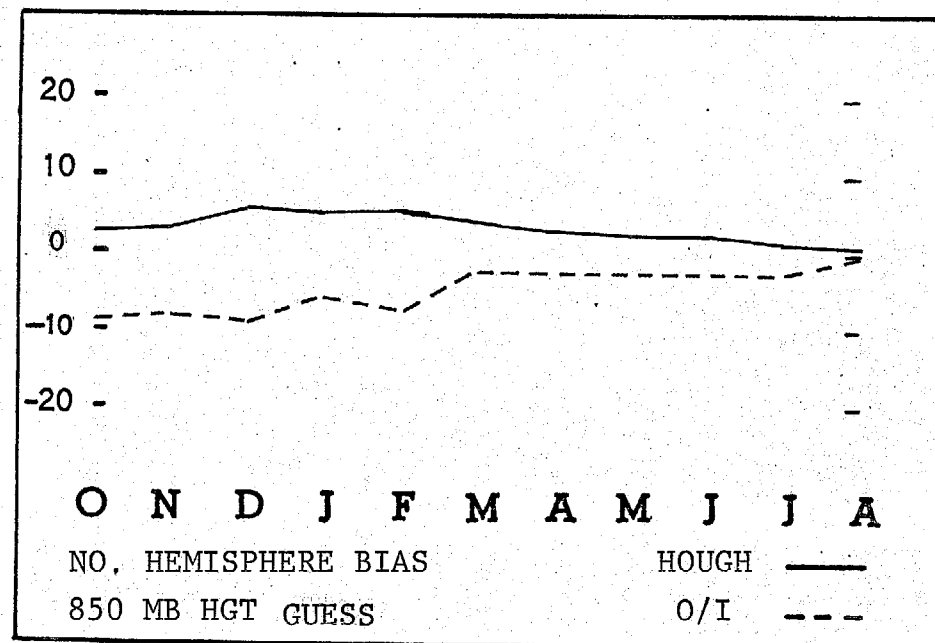
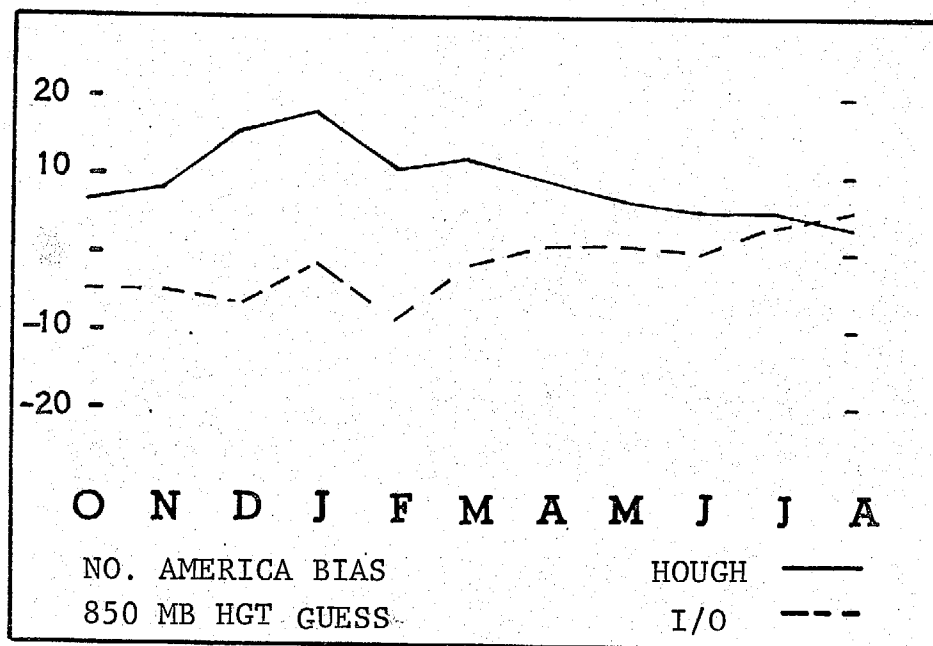
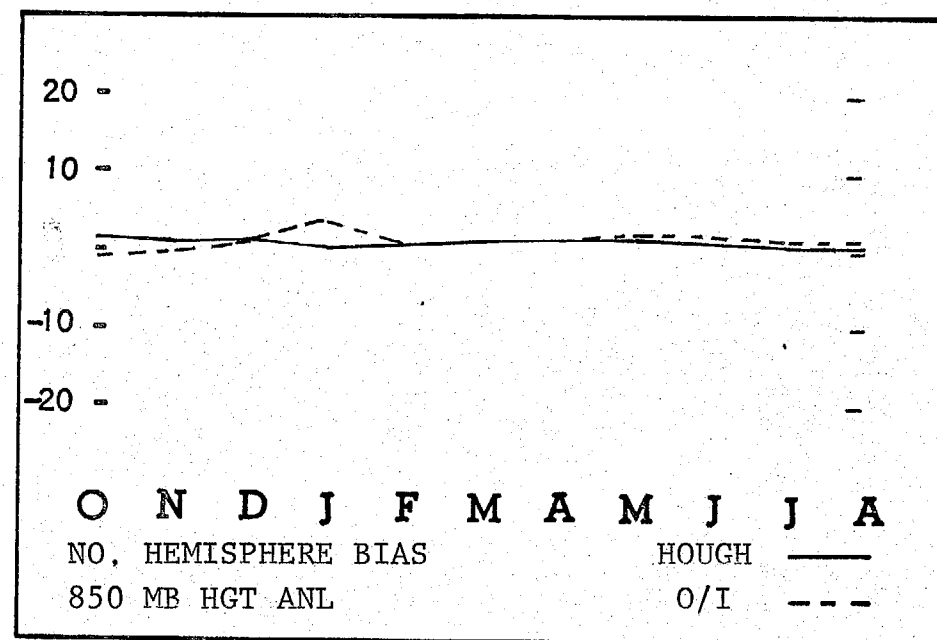
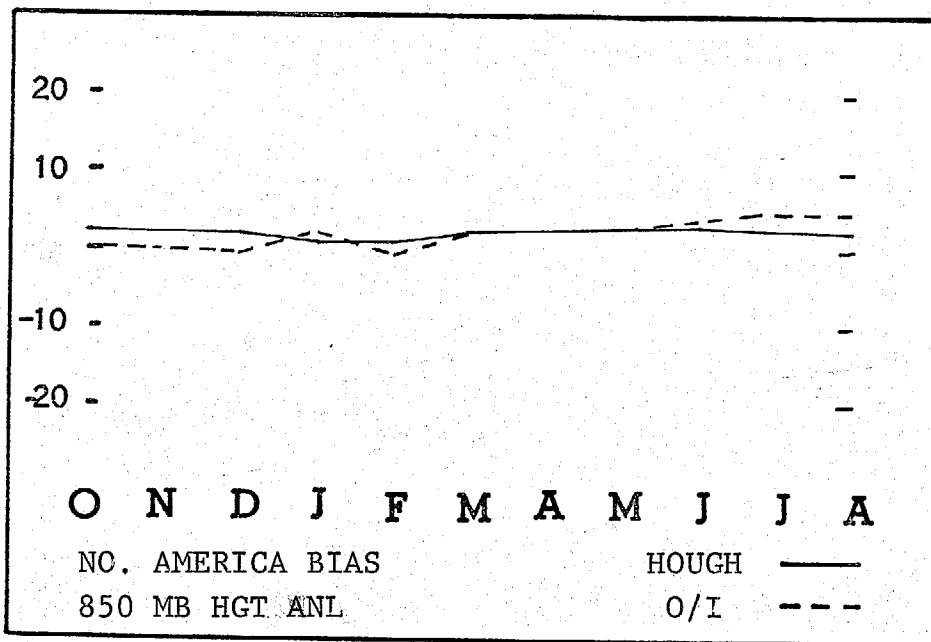
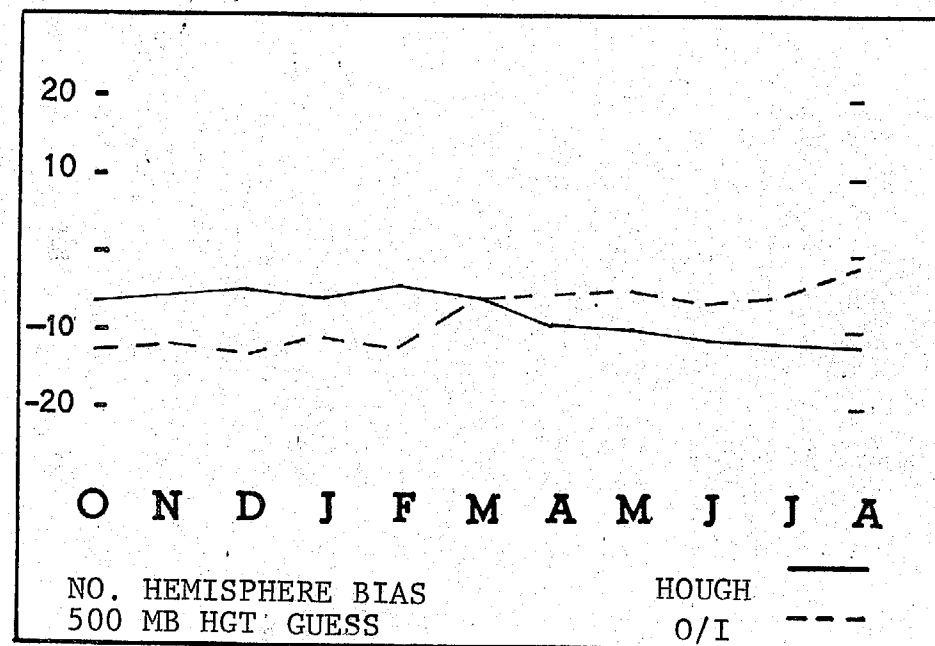
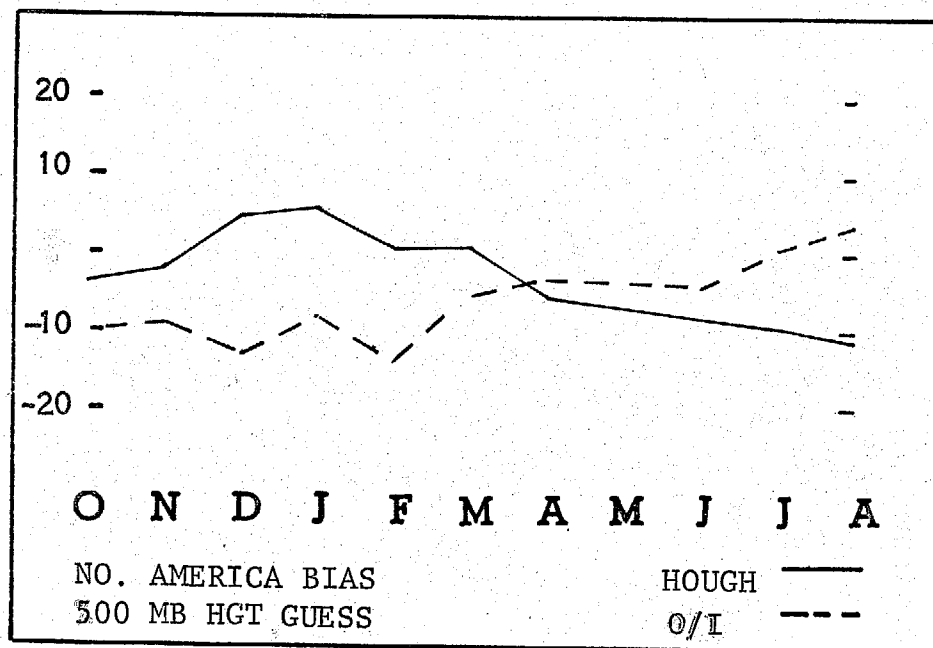
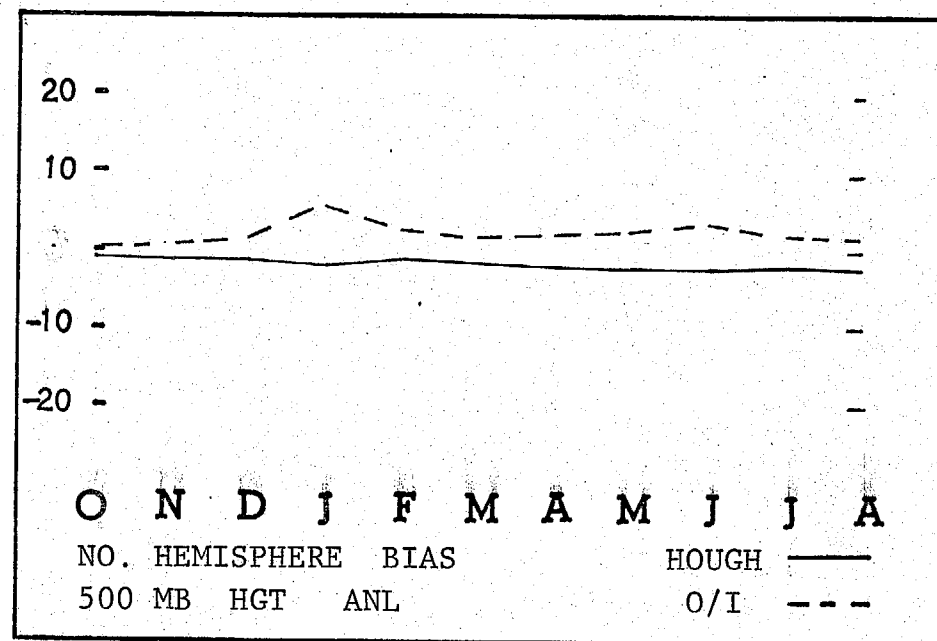
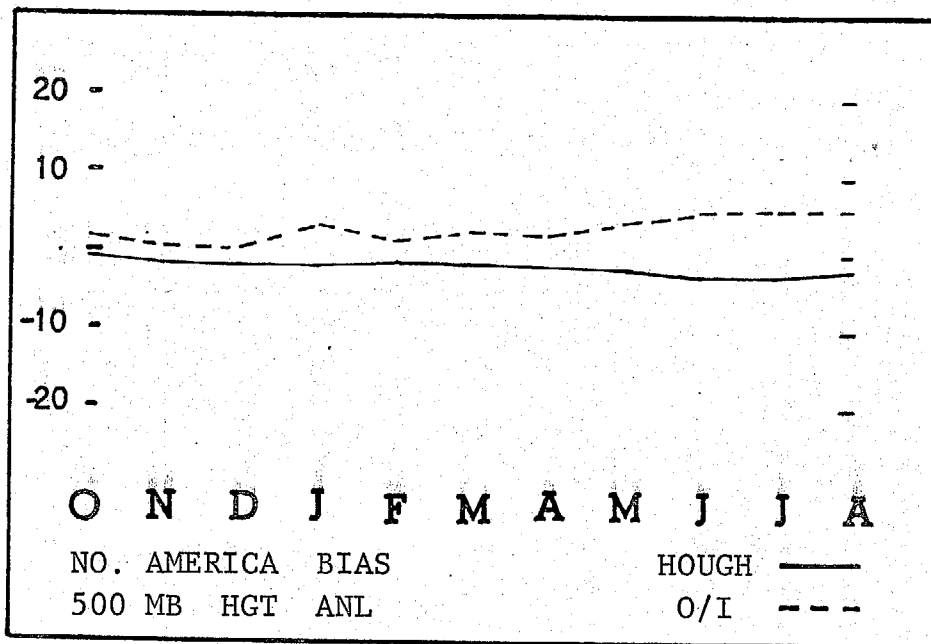


Fig 4a



Lj 45

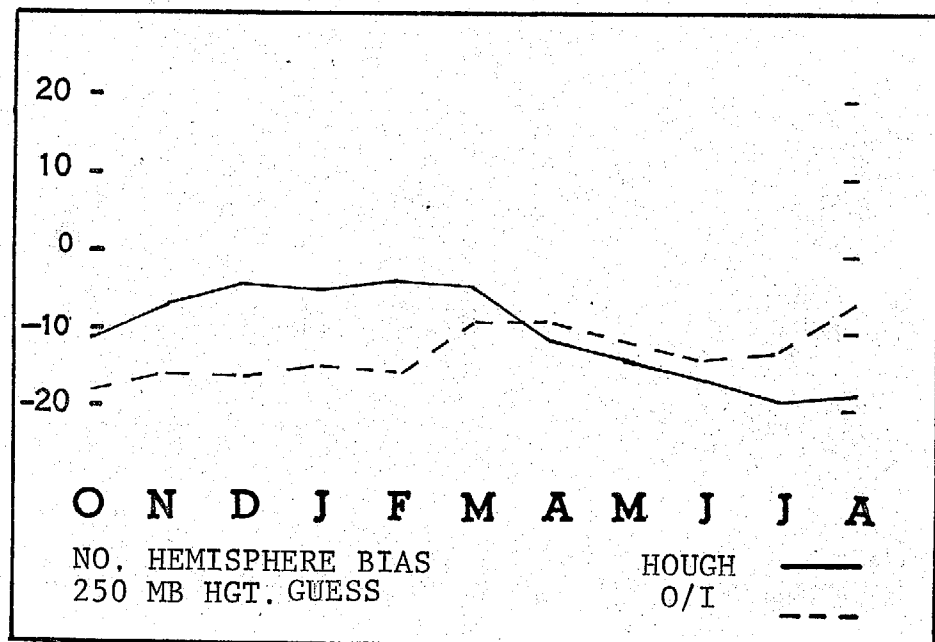
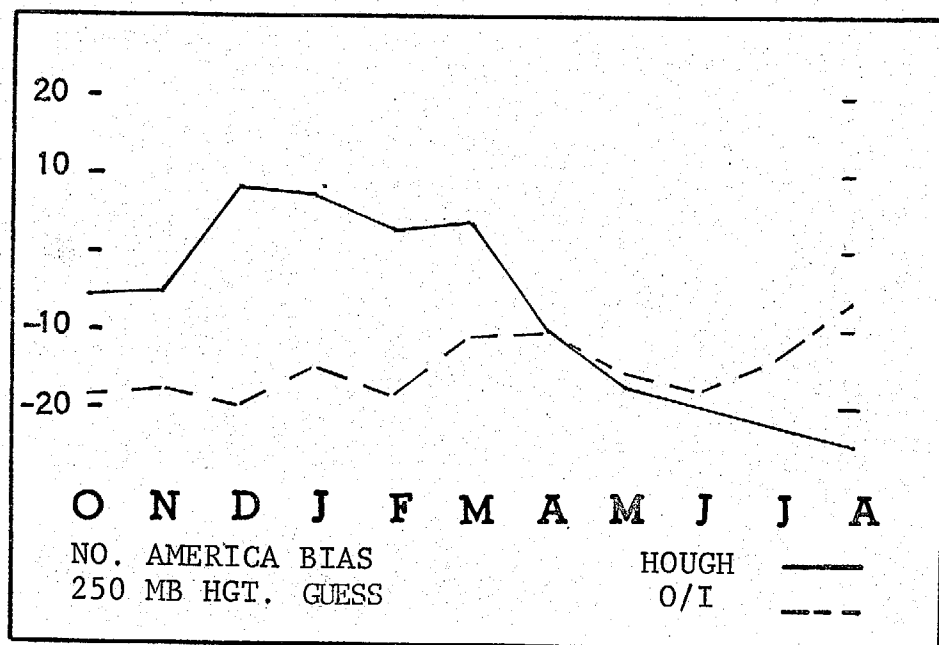
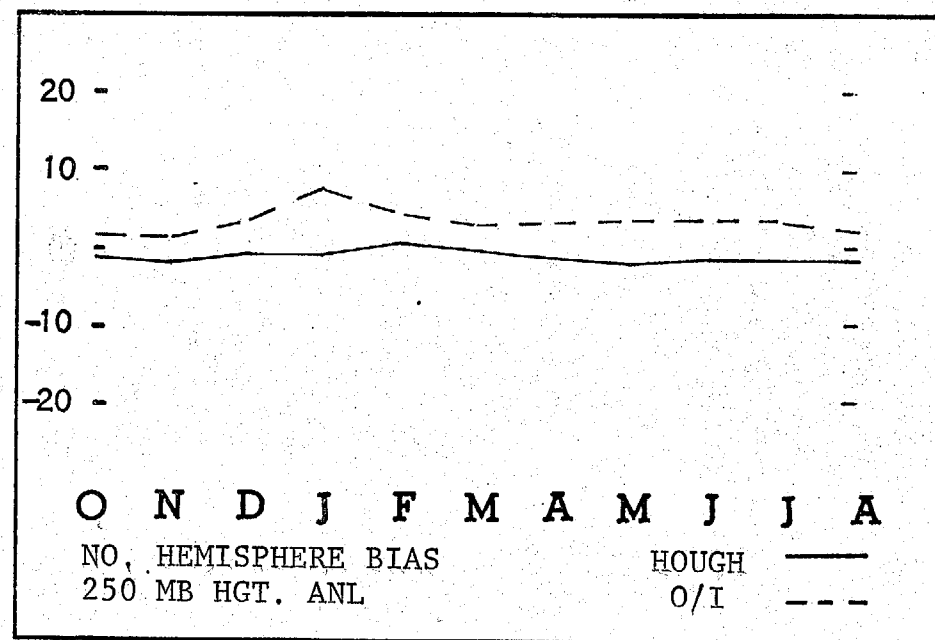
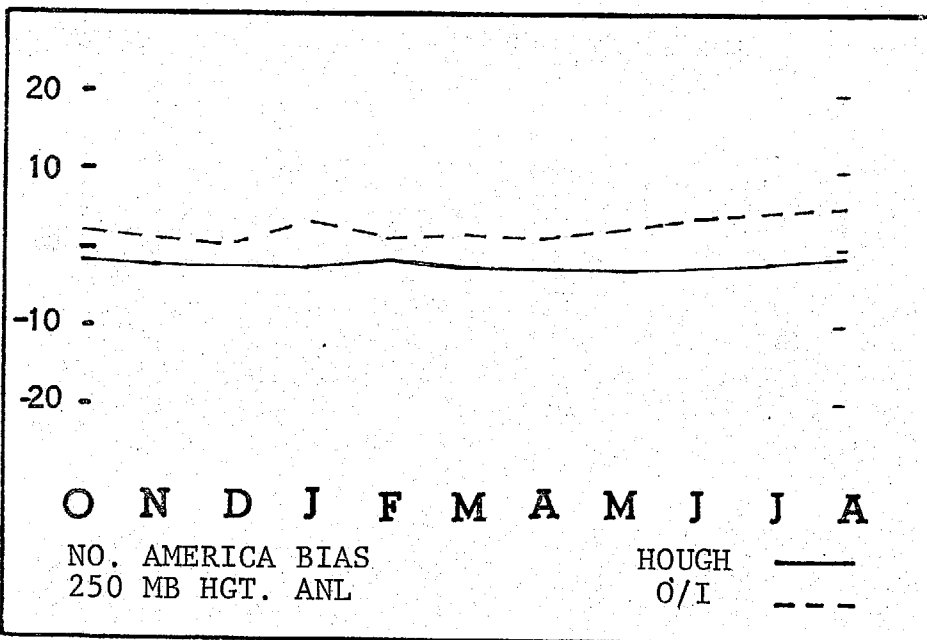


Fig 4c

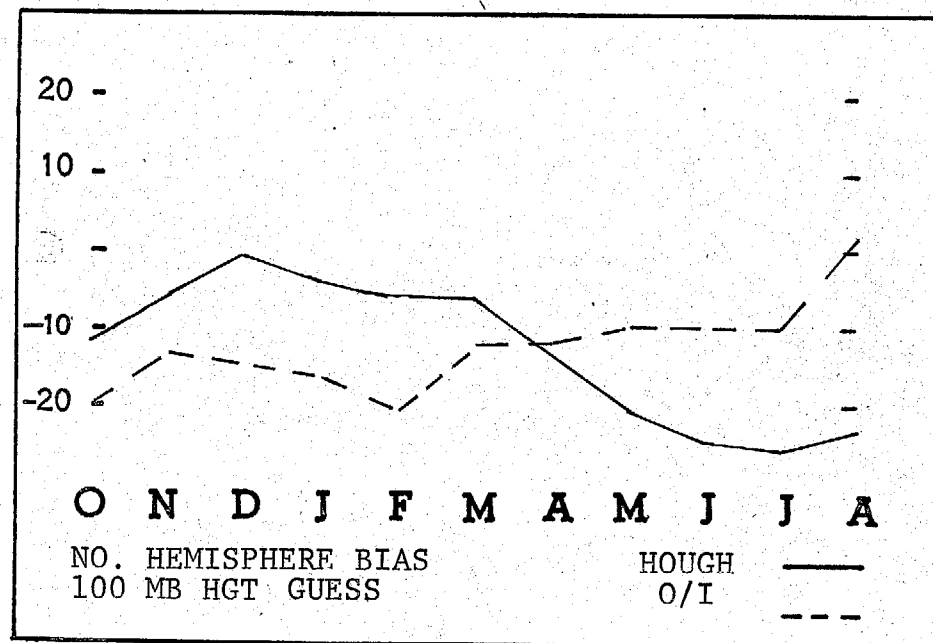
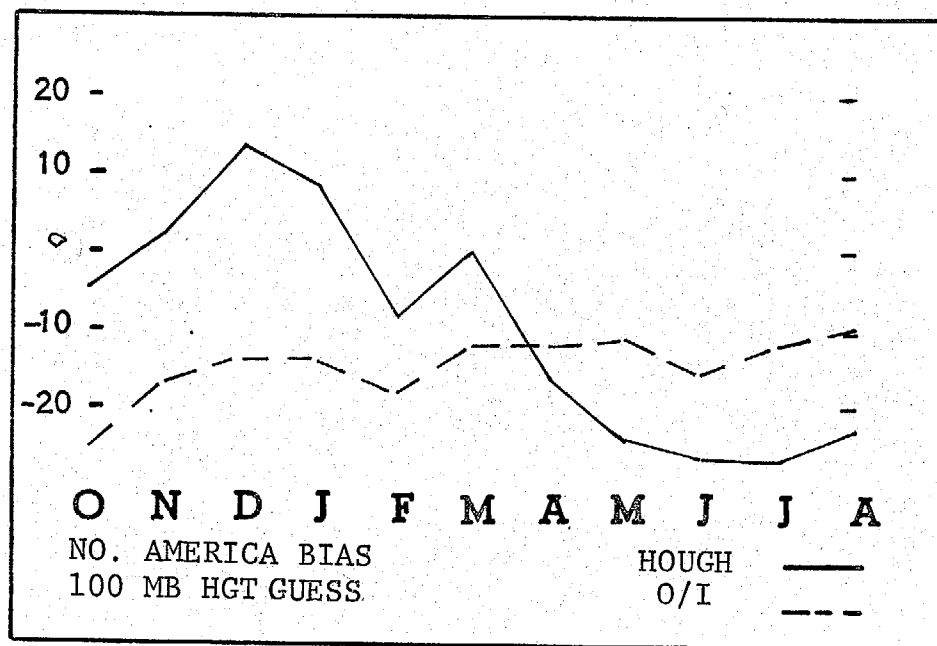
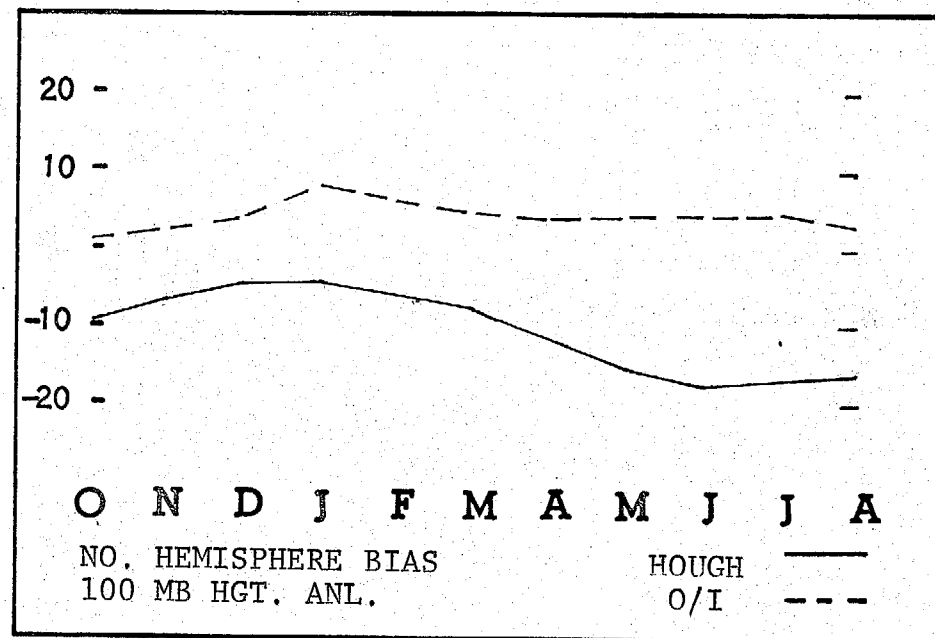
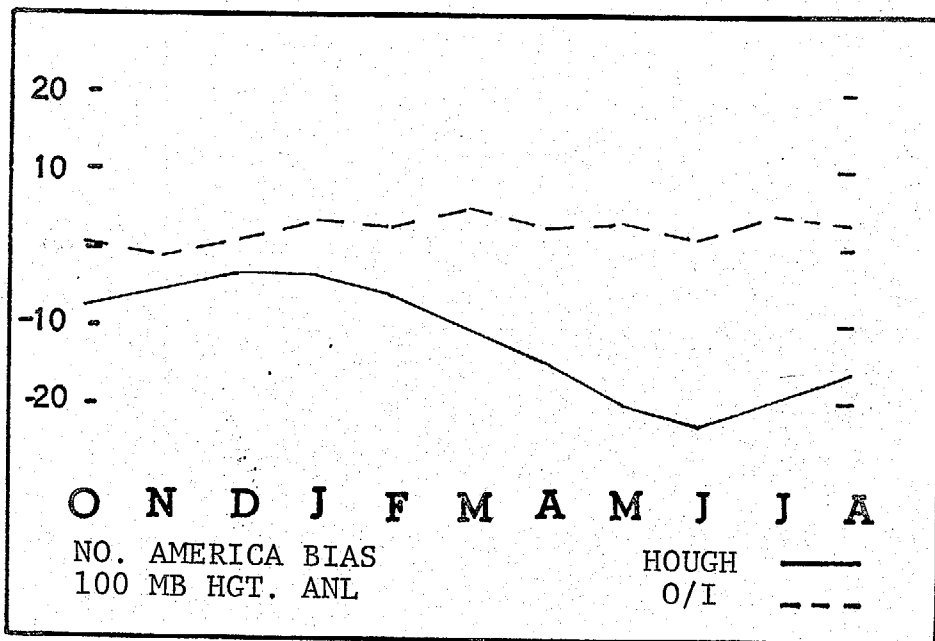


Fig 4d

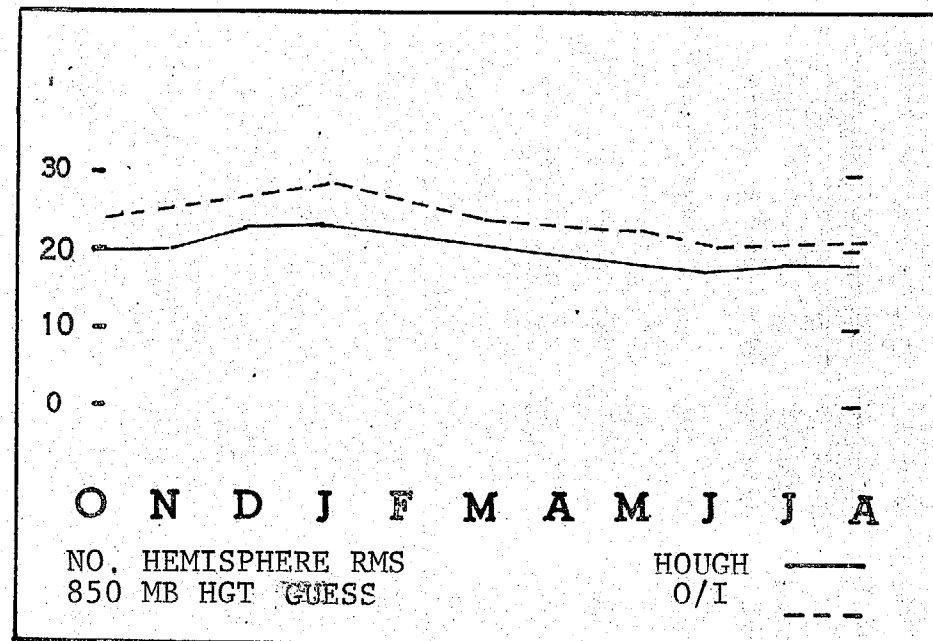
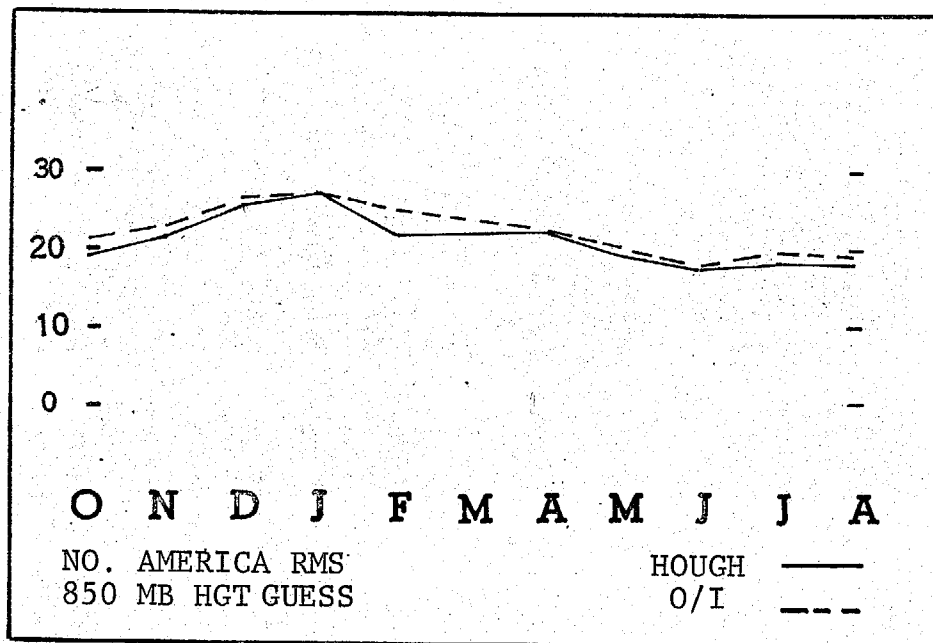
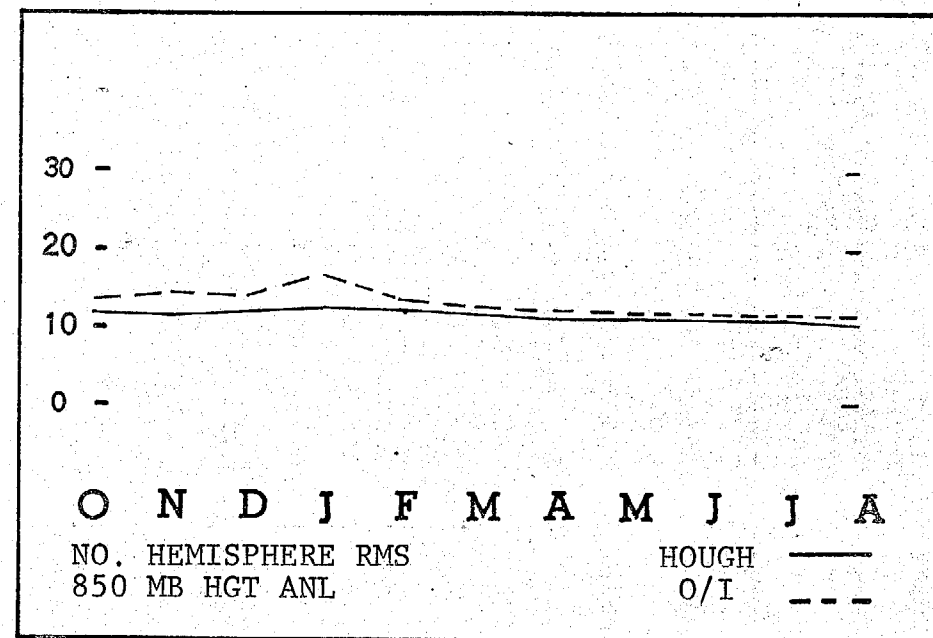
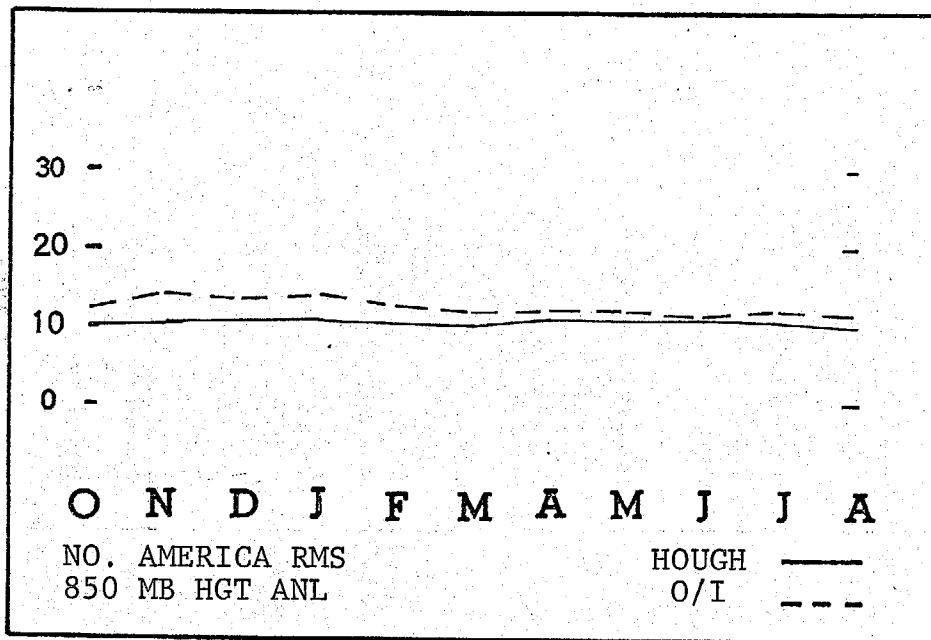
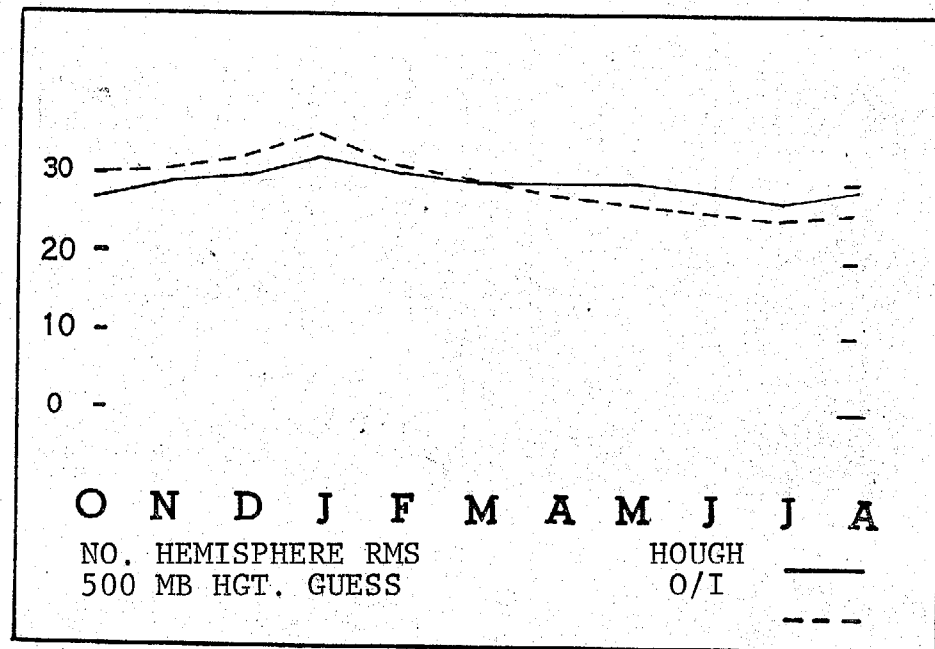
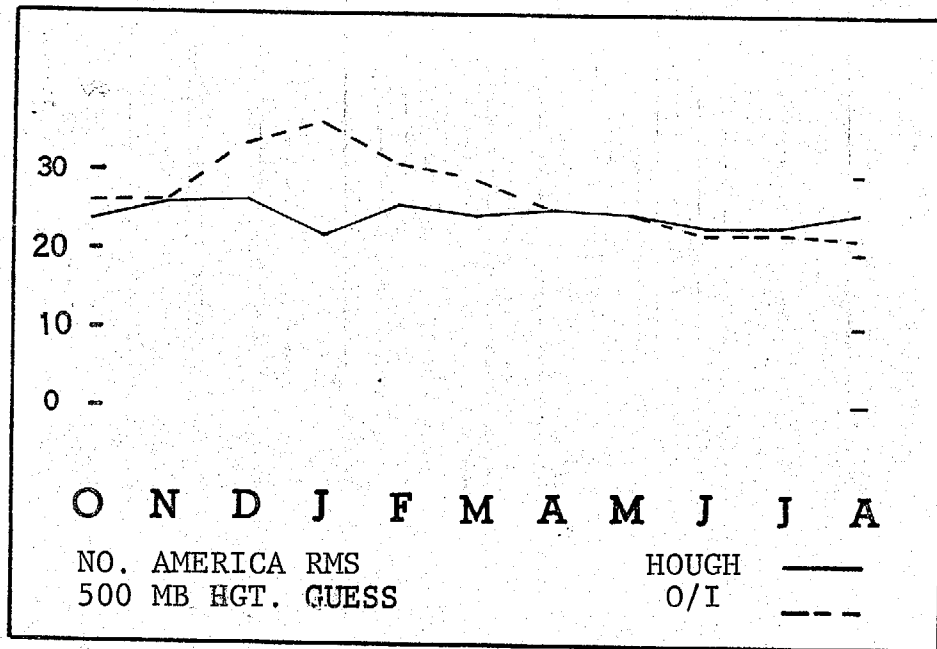
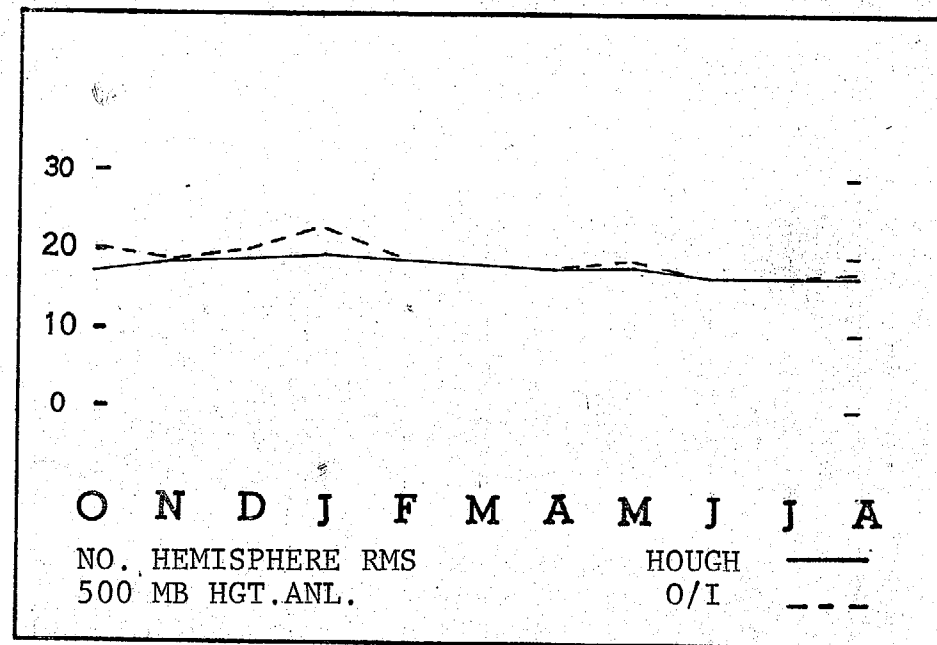
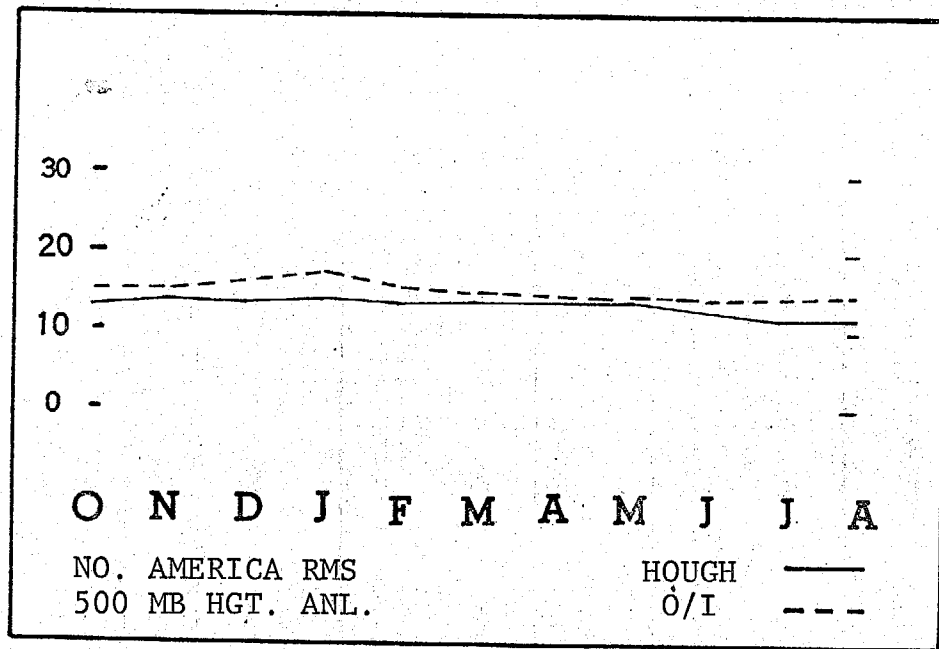
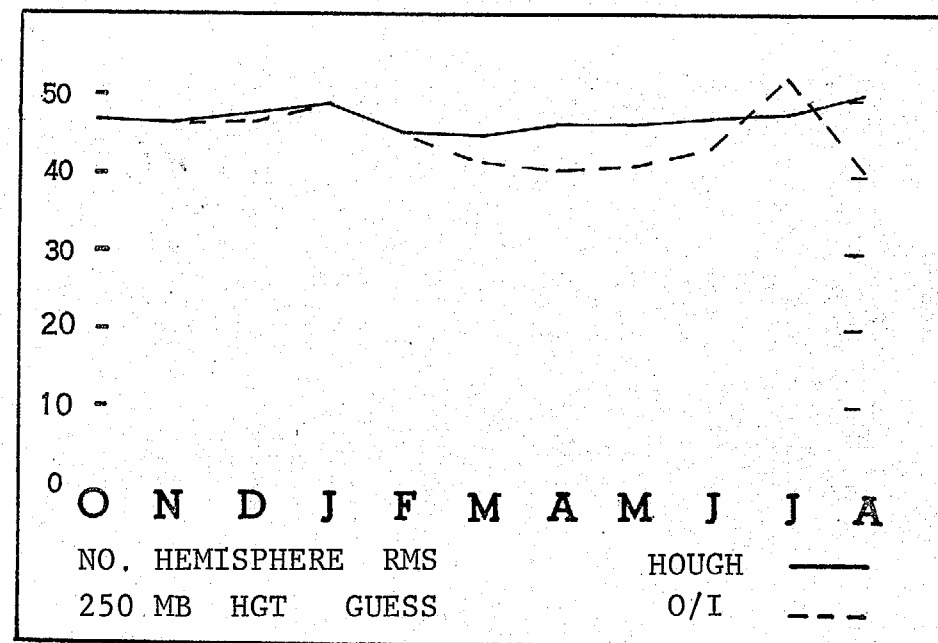
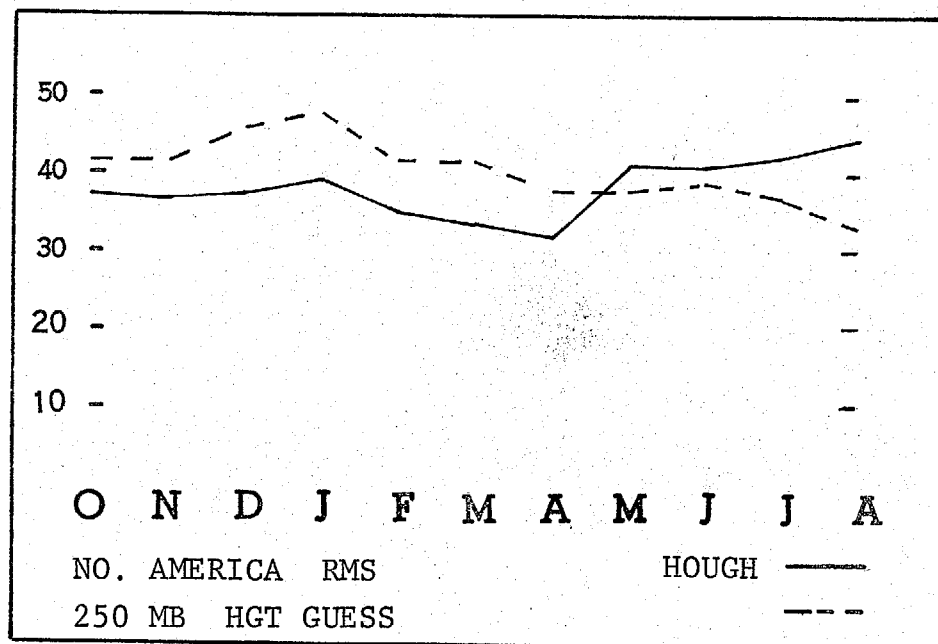
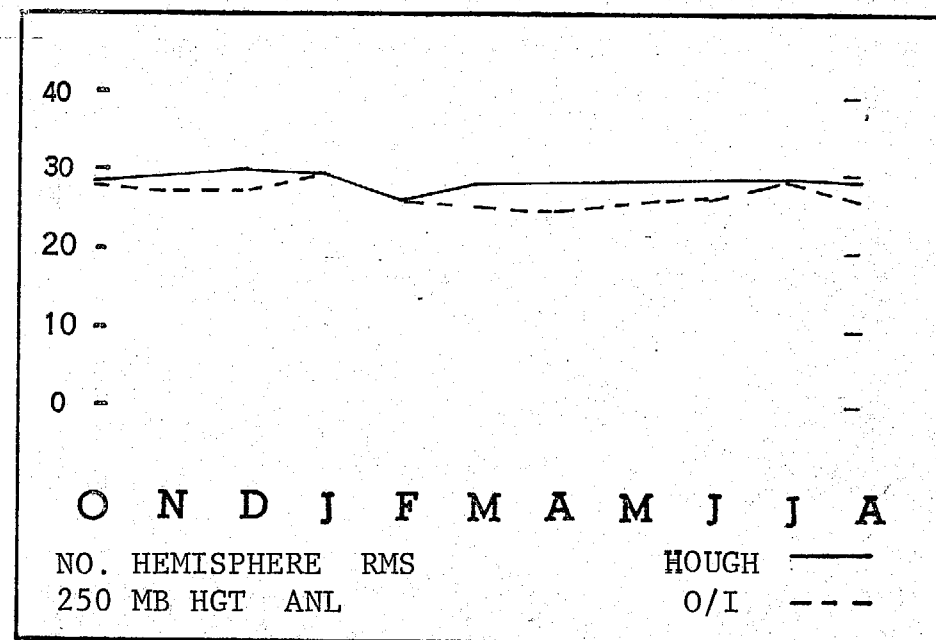
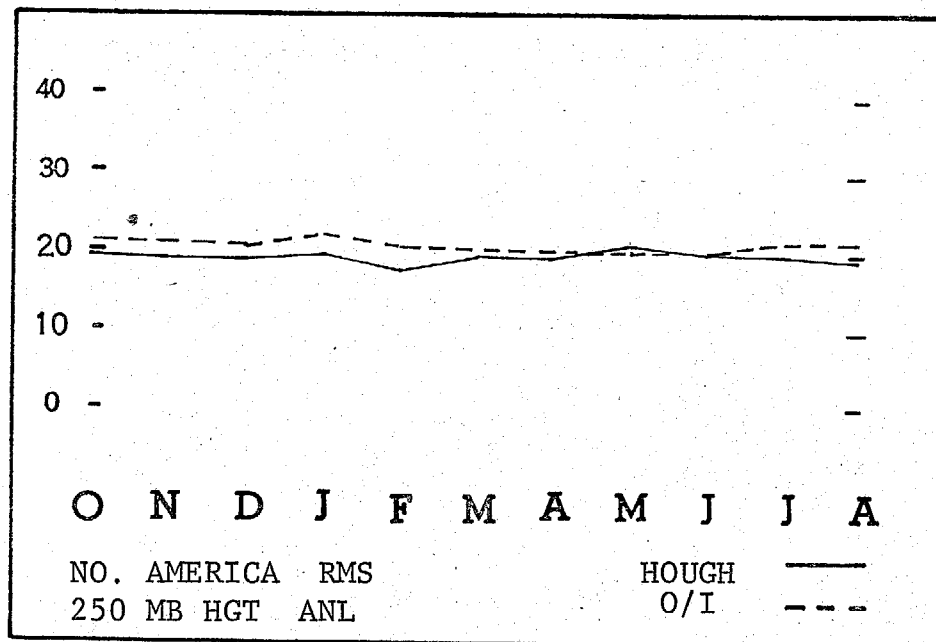


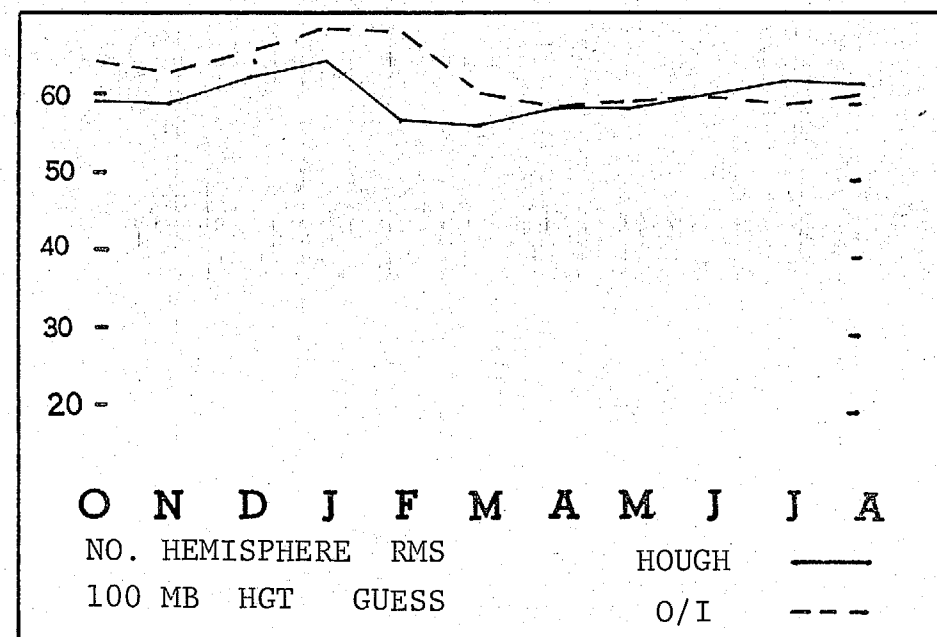
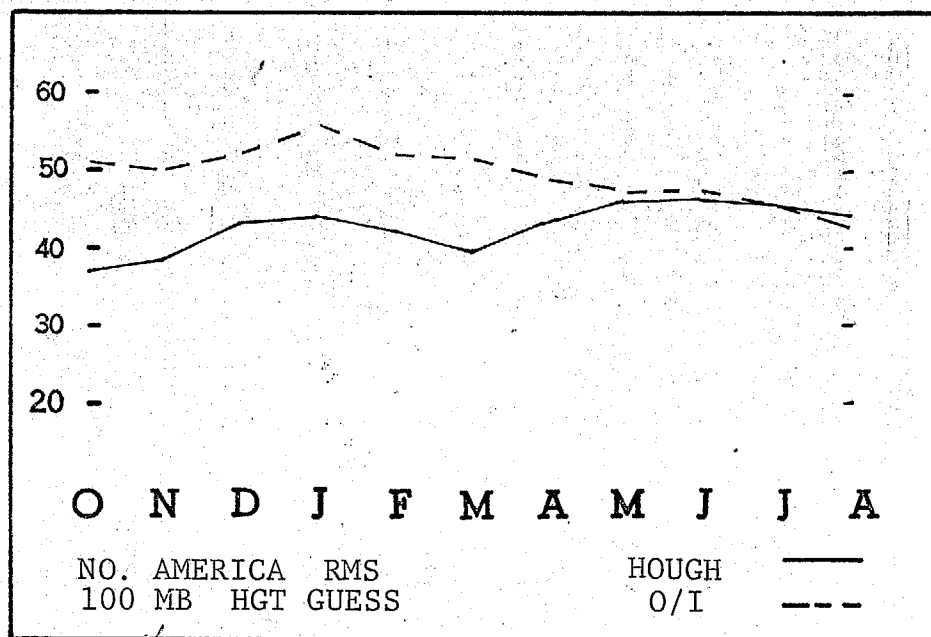
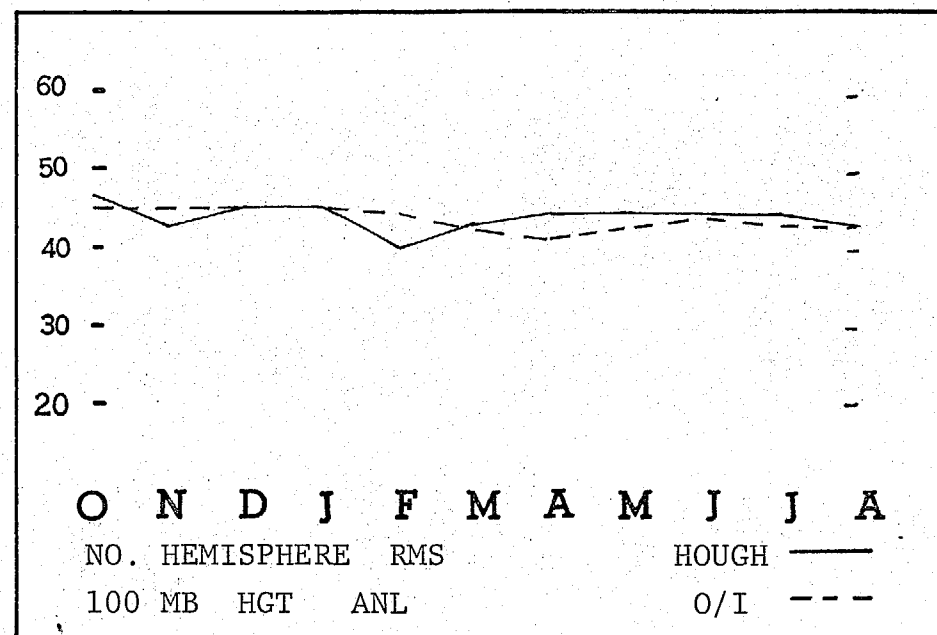
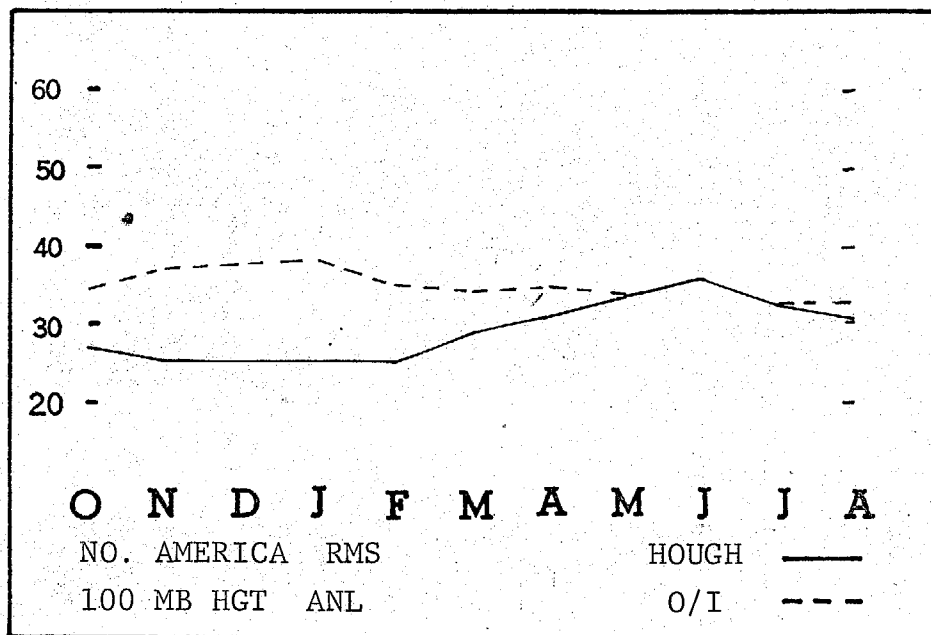
Fig 5

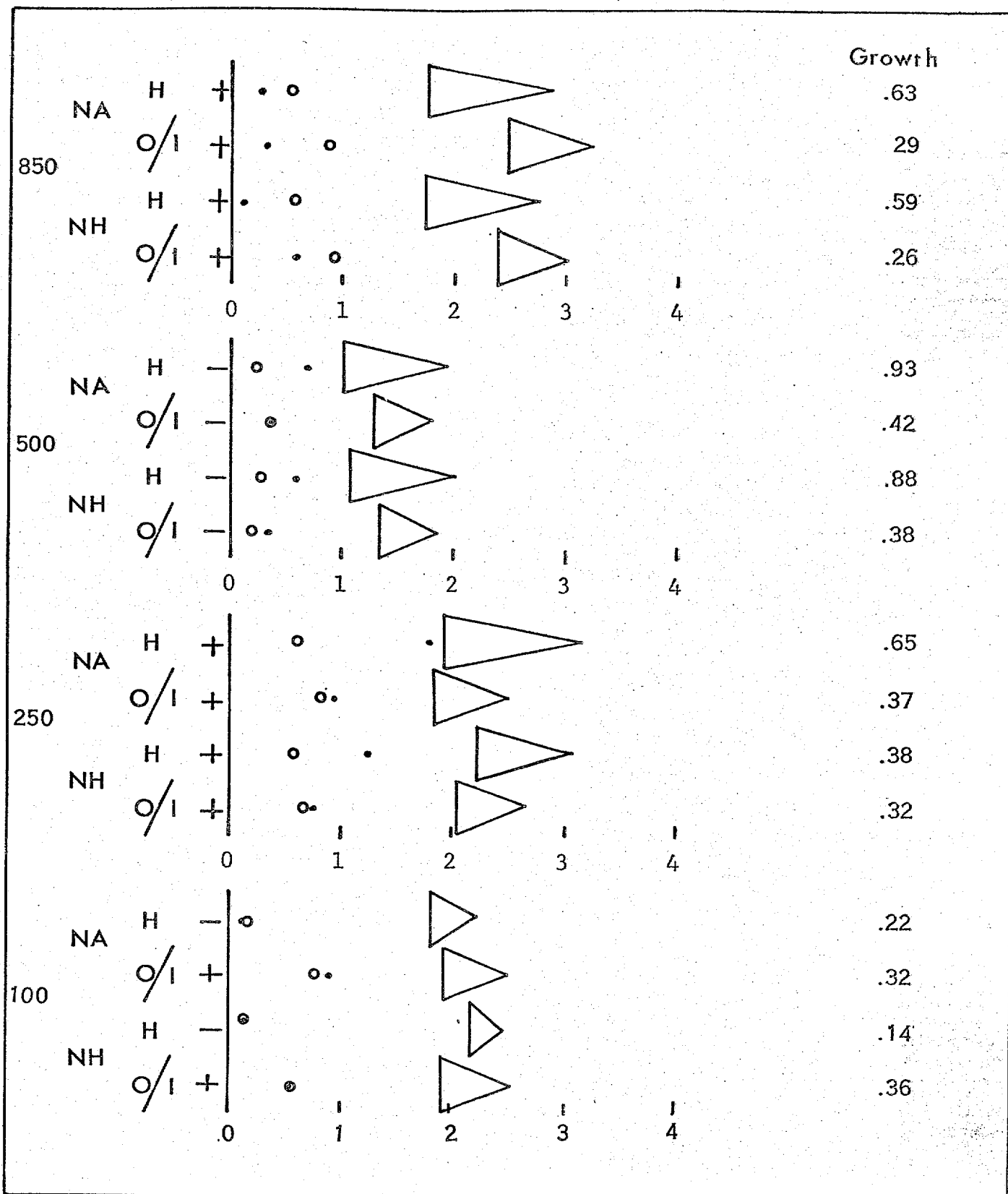


Lij



Jy 50





11 MONTH AVERAGE TEMPERATURE DEVIATIONS °K

o ANALYSIS BIAS (all positive)

. GUESS BIAS (sign as indicated)



$$\text{GROWTH} \equiv \left[\frac{G - A}{A} \right]$$

Fig 6

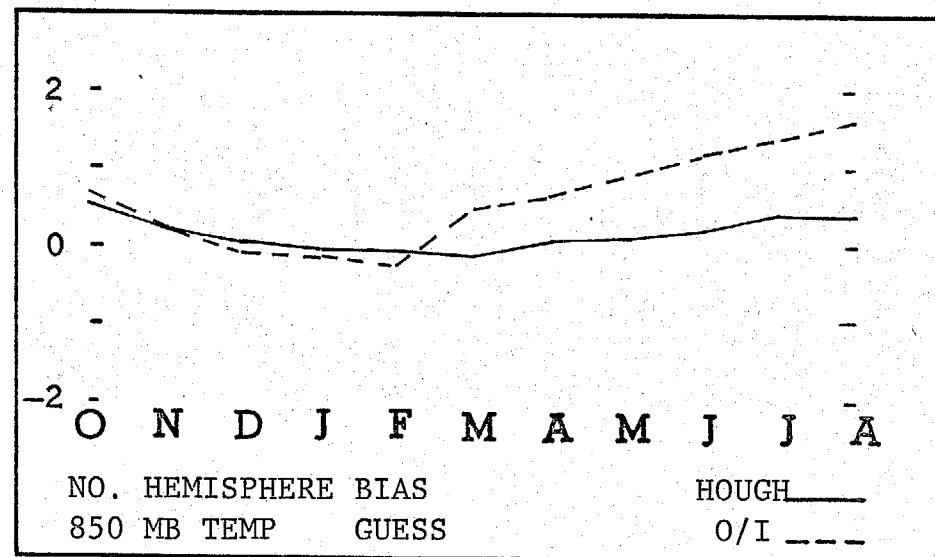
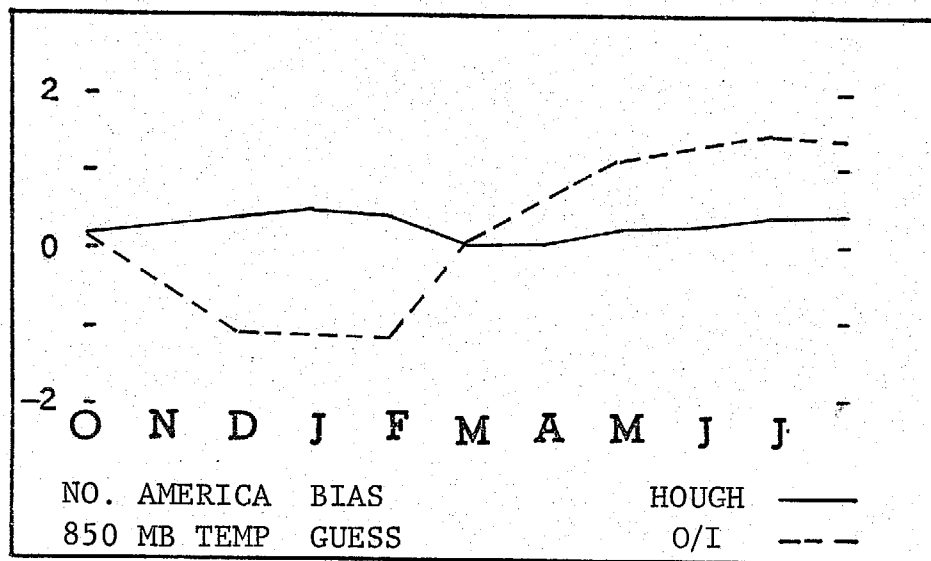
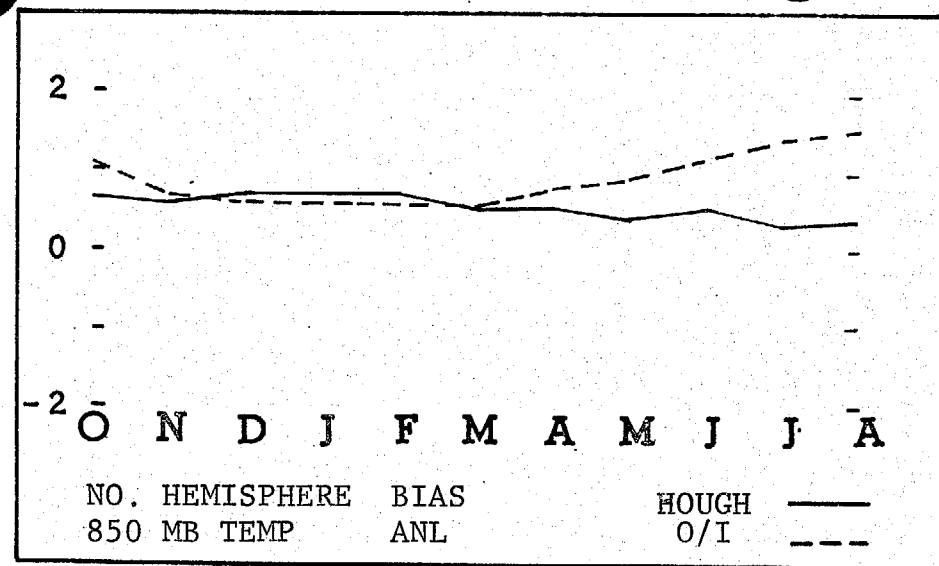
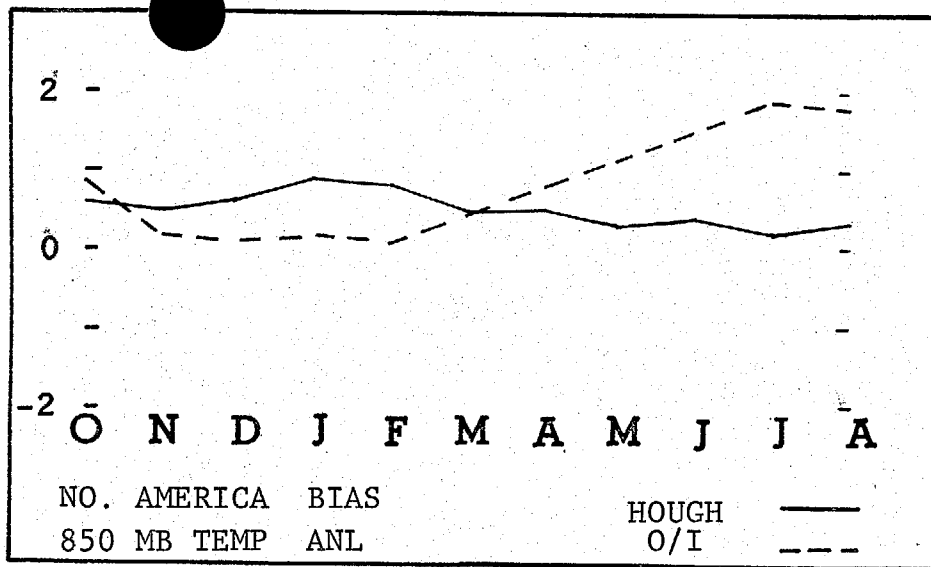


fig 1a

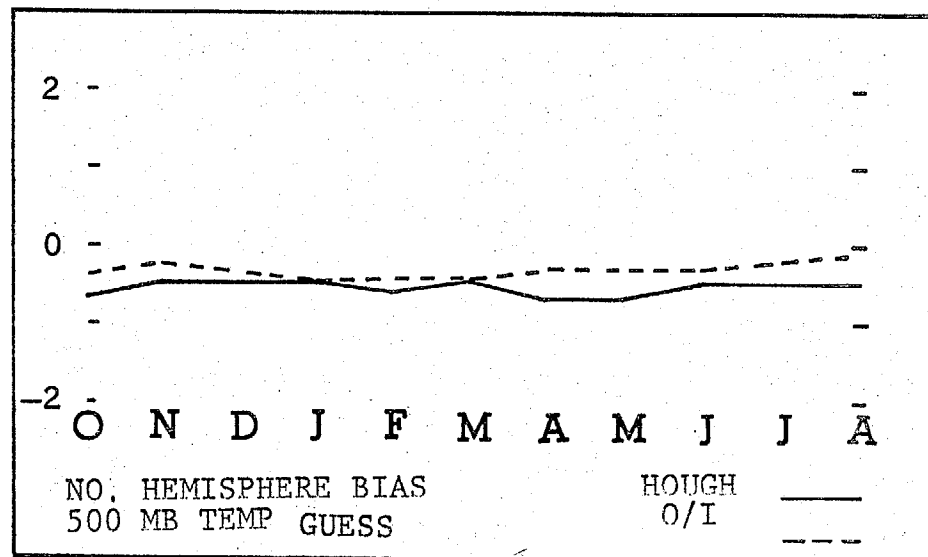
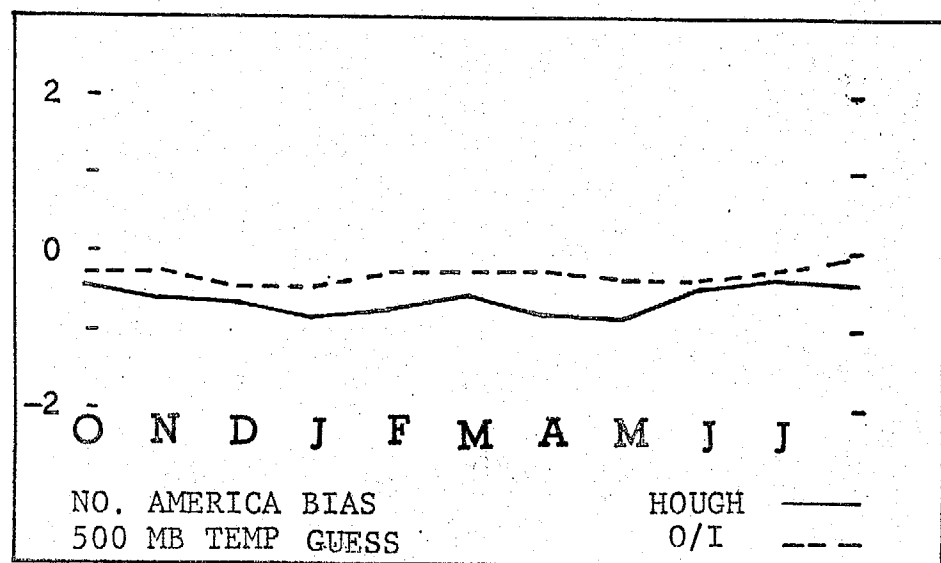
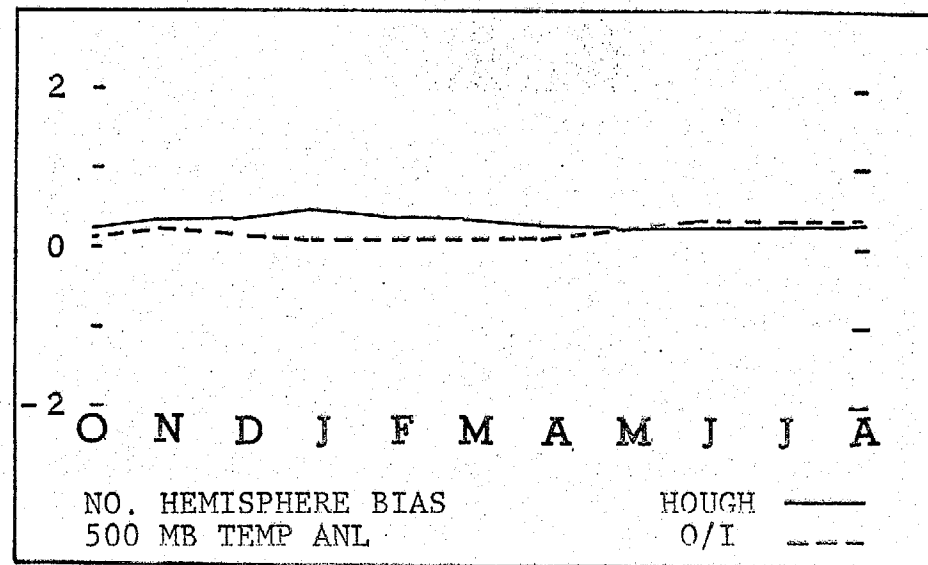
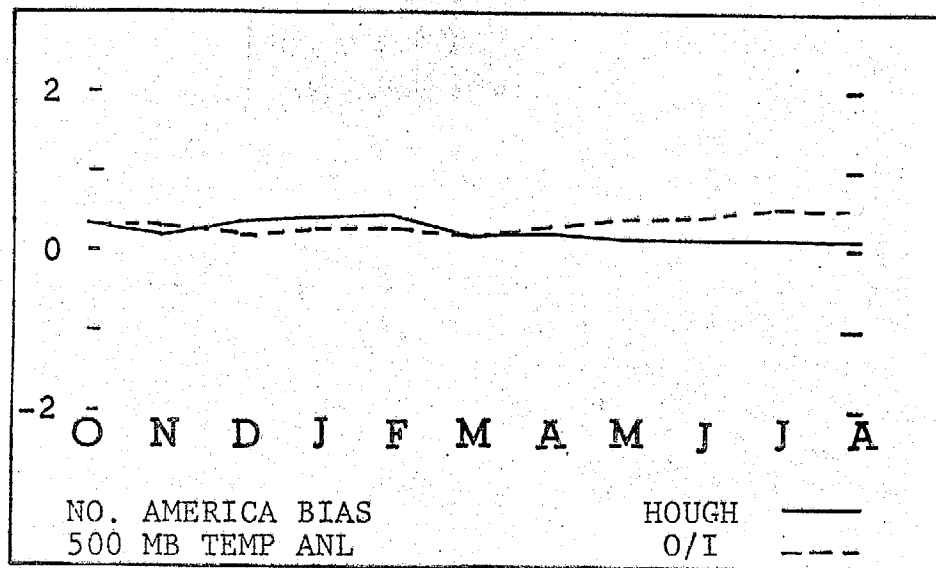
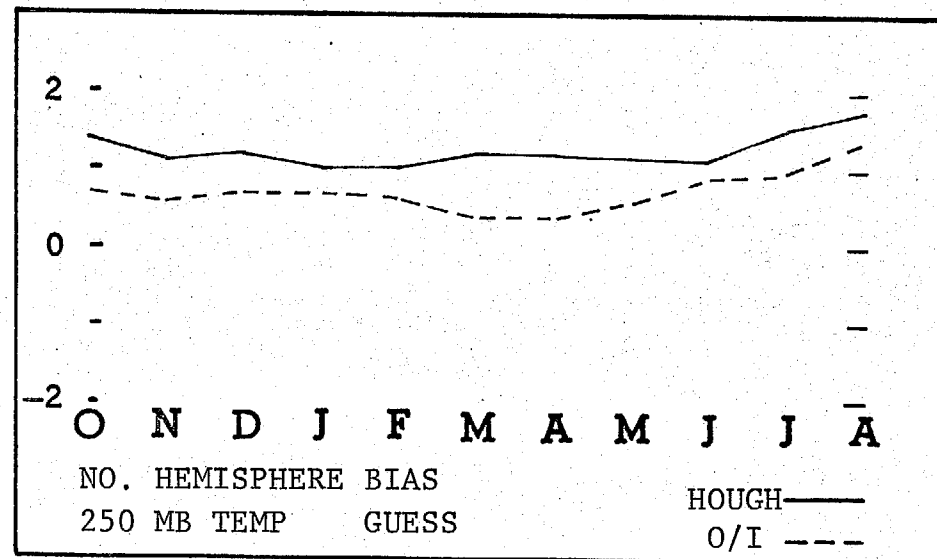
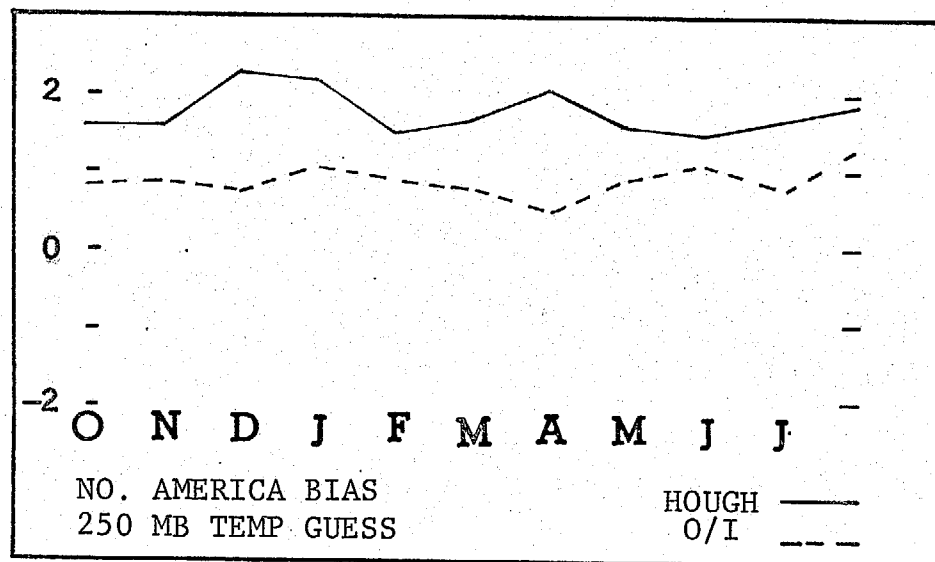
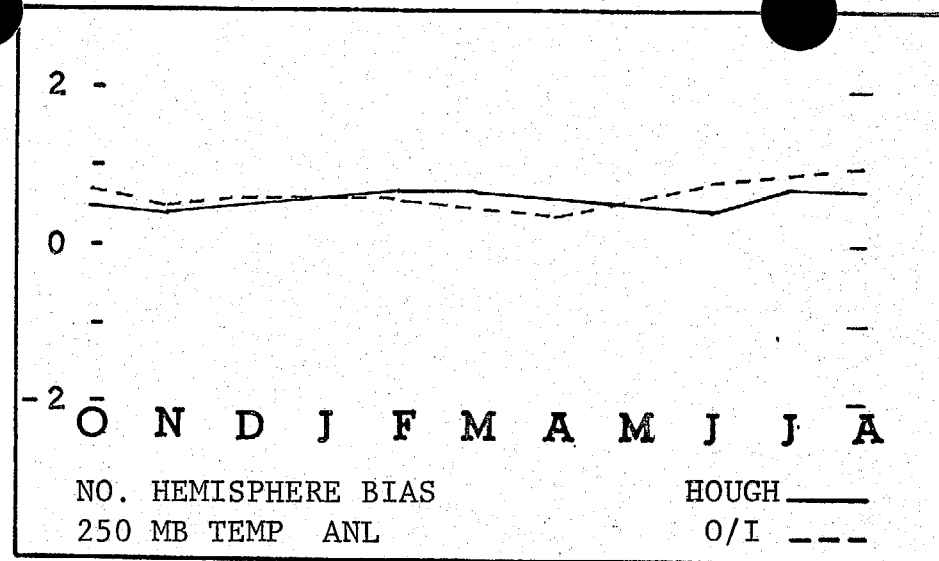
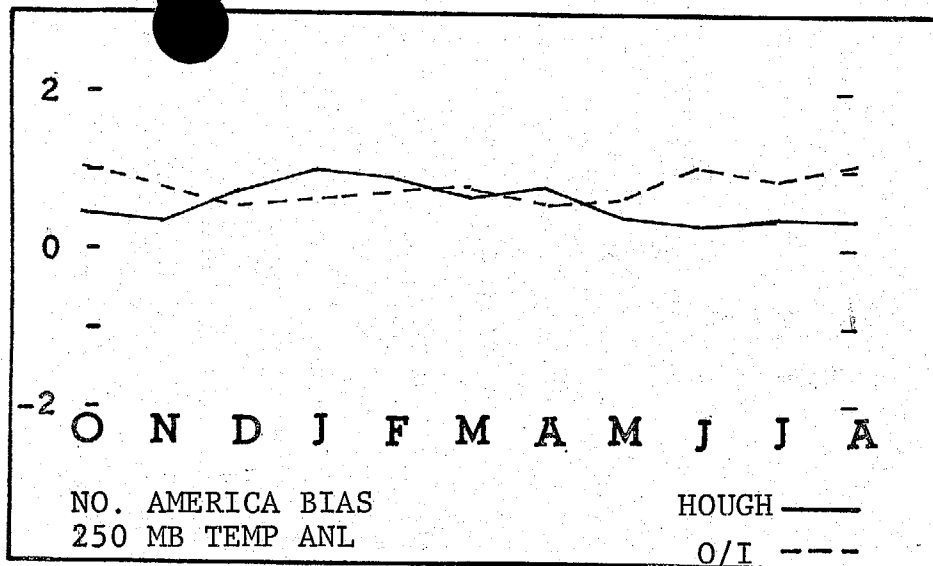


Fig 76



Lij 7c

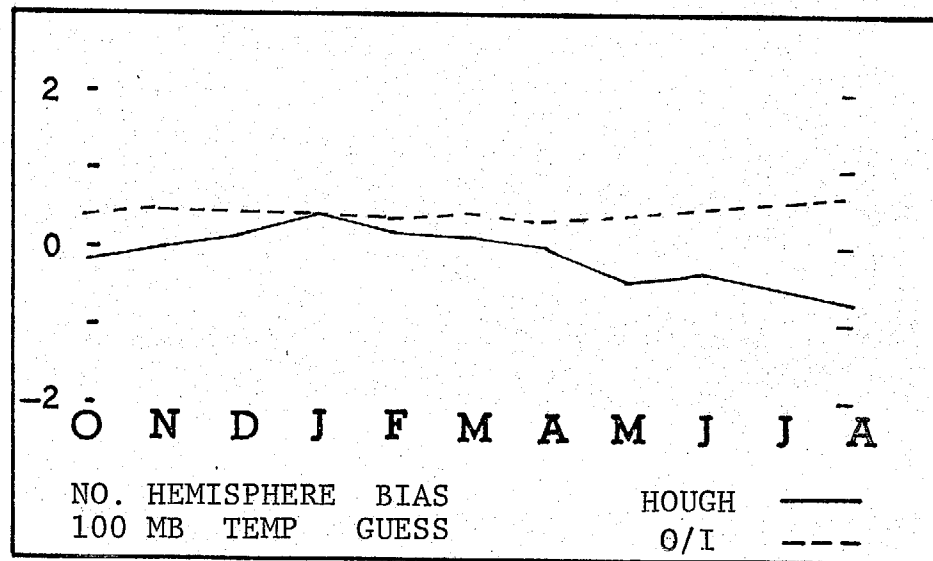
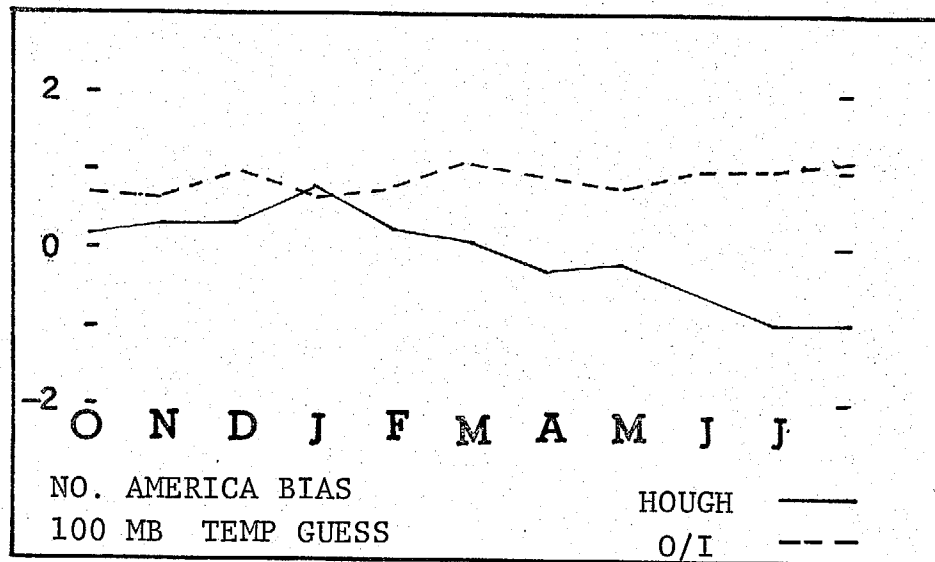
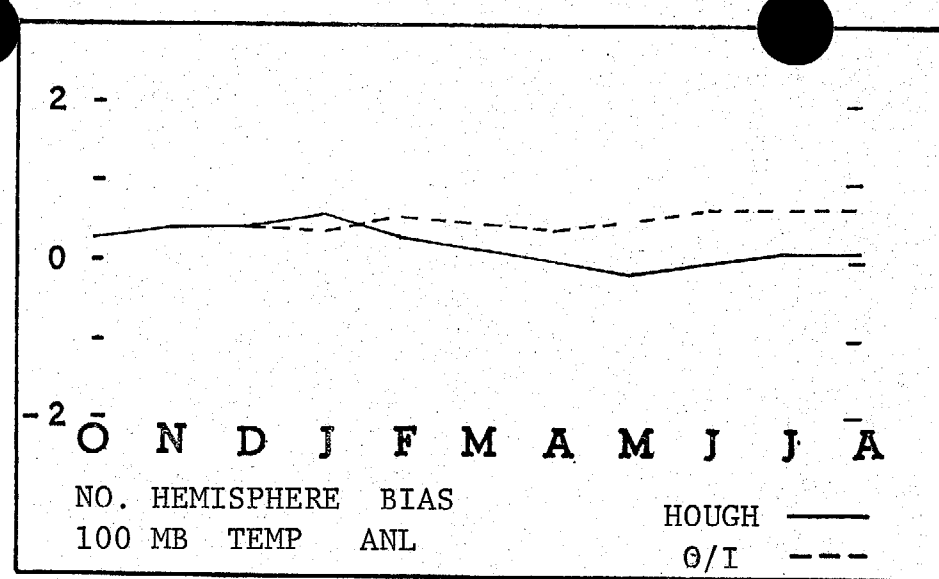
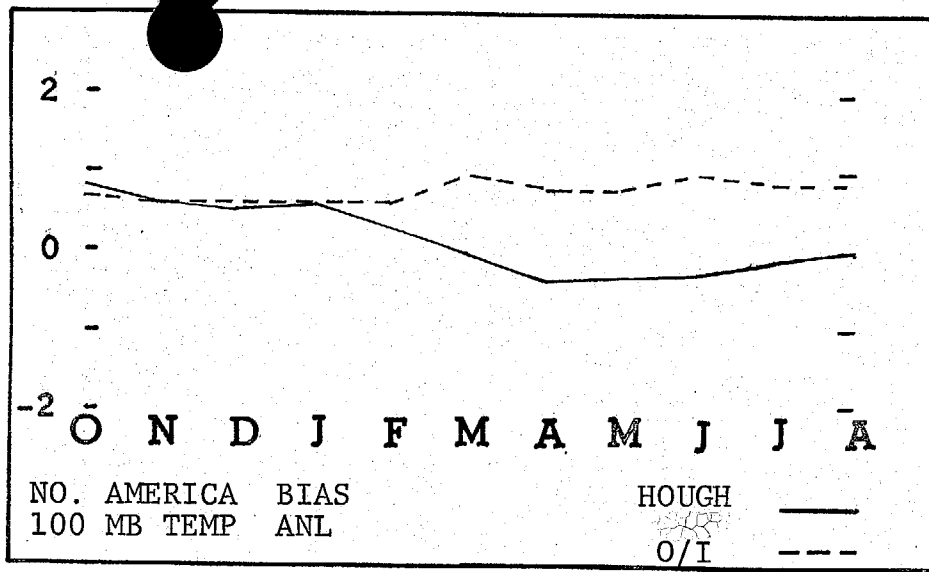


Fig 7d

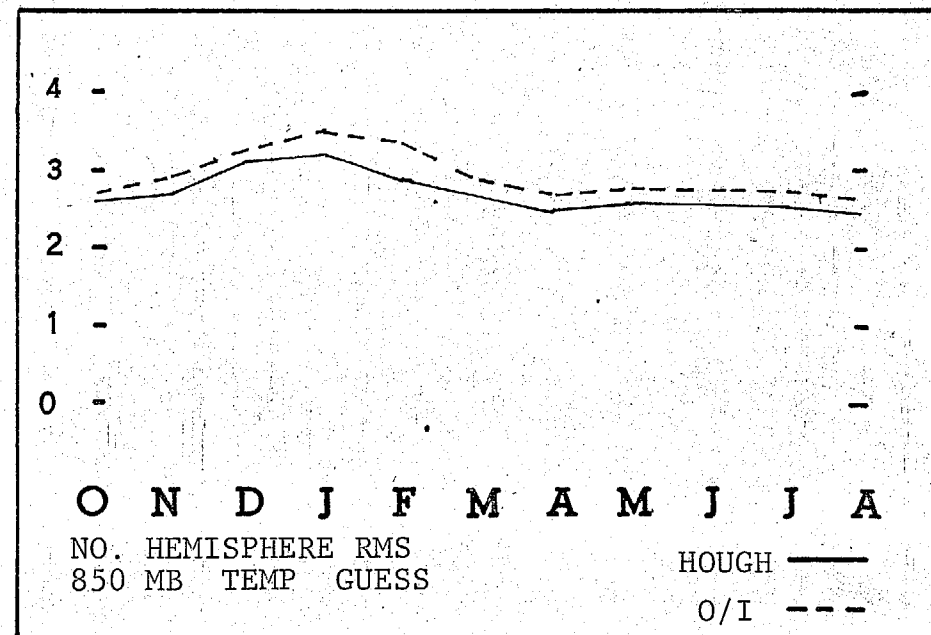
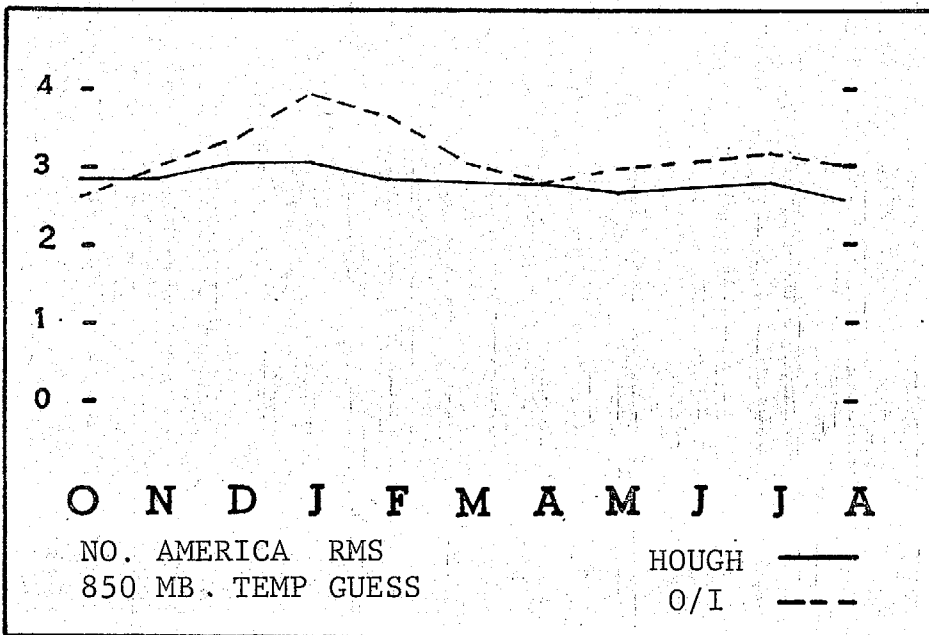
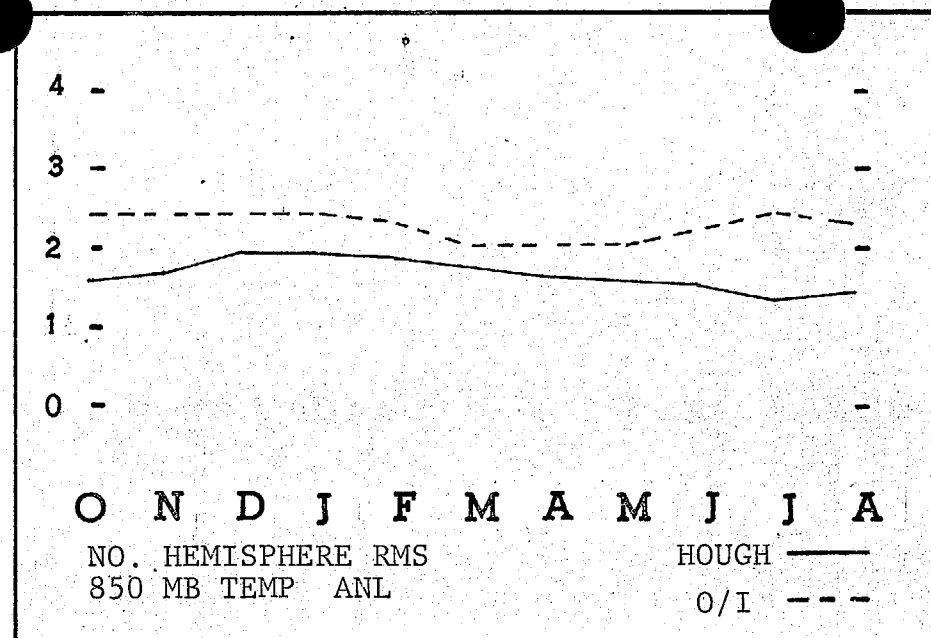
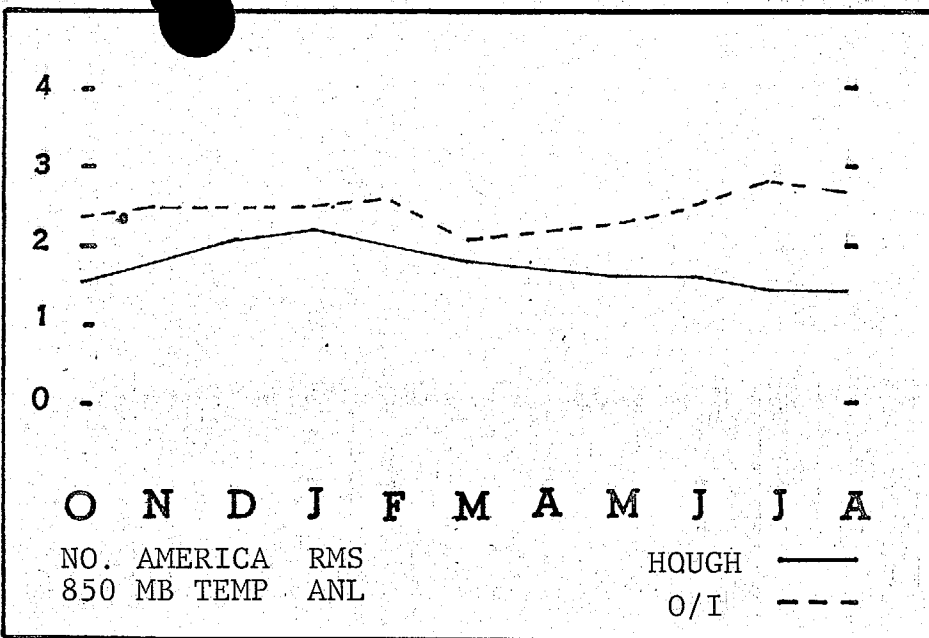


Fig 8a

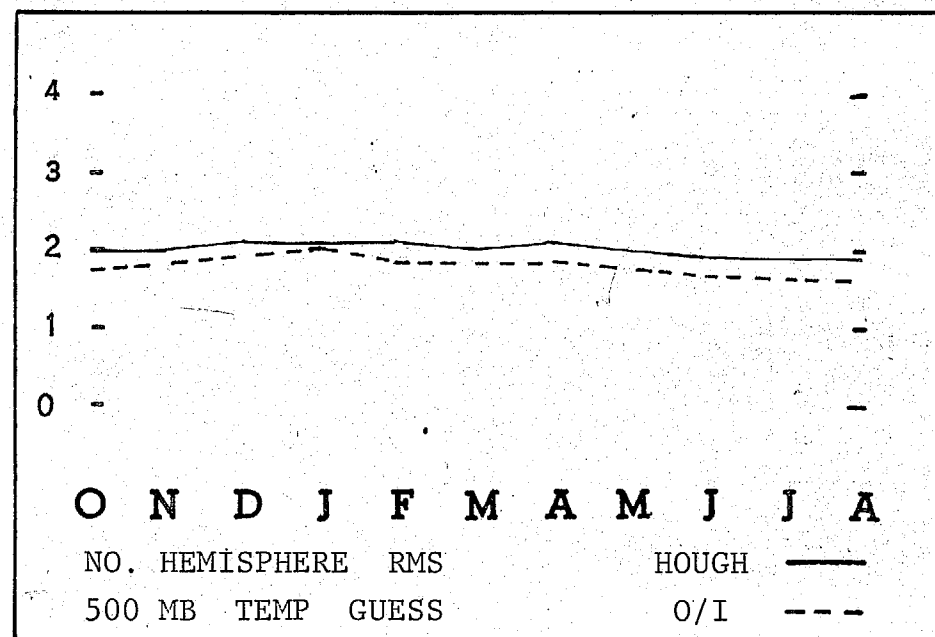
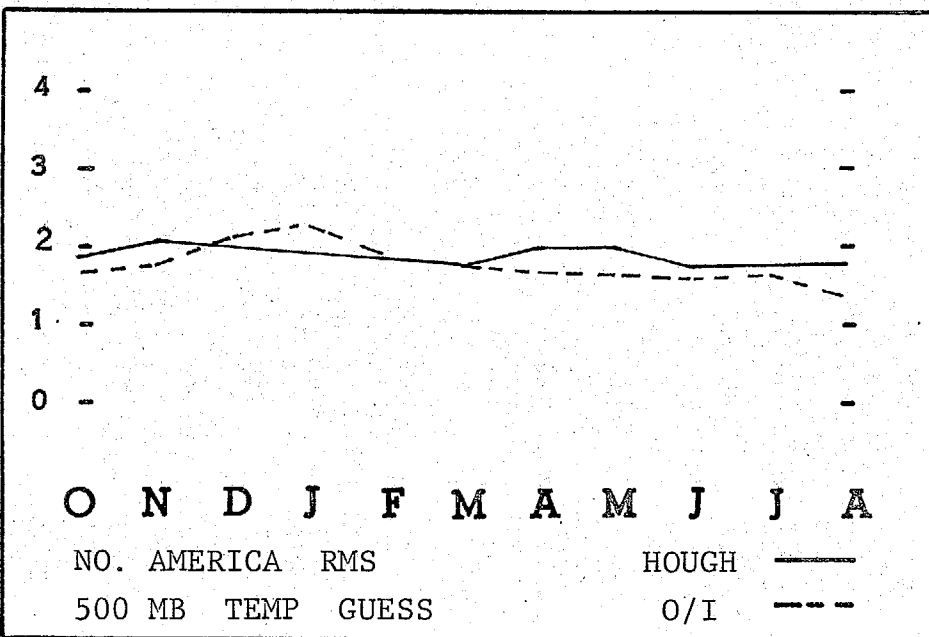
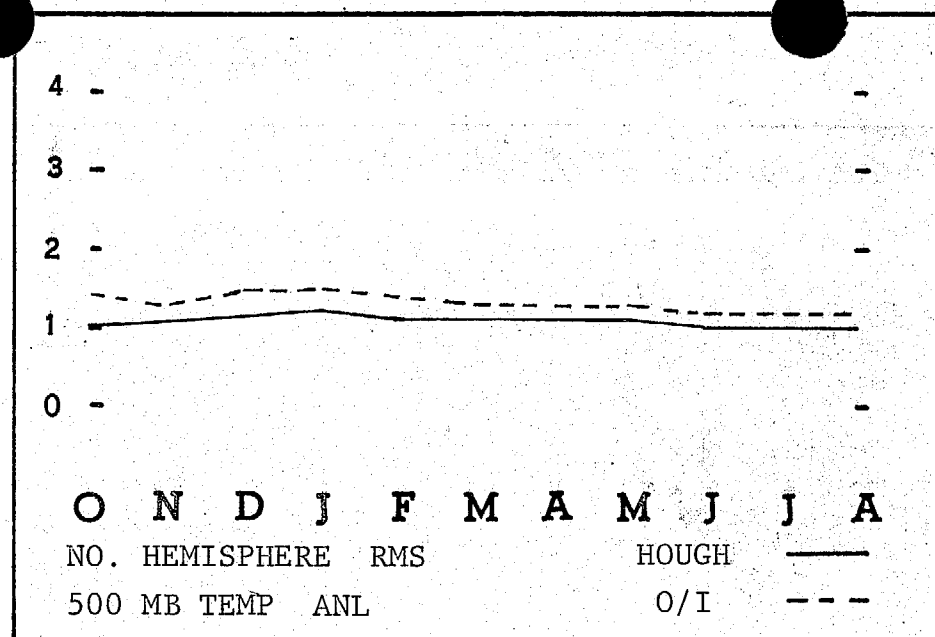
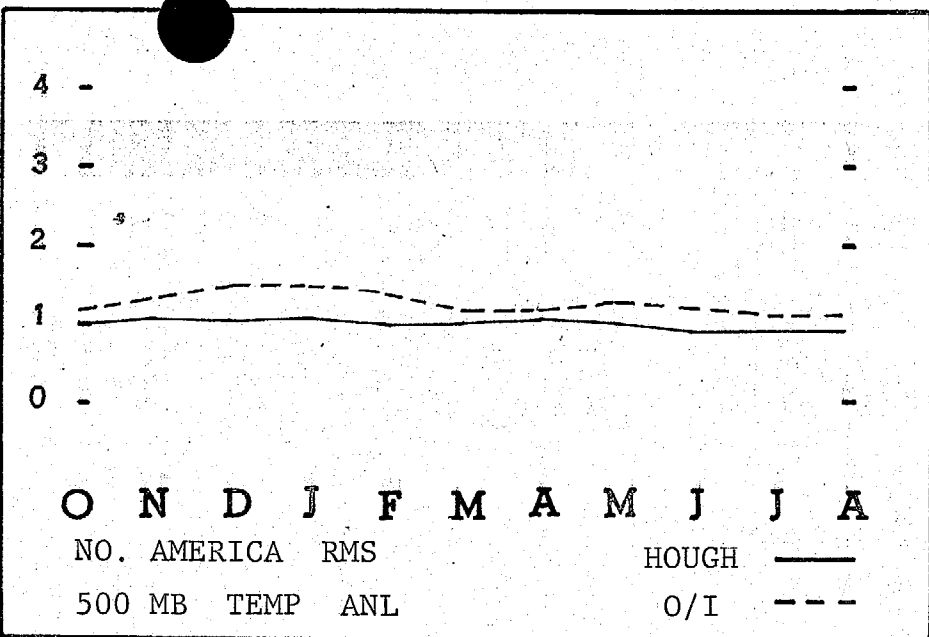


Fig 86

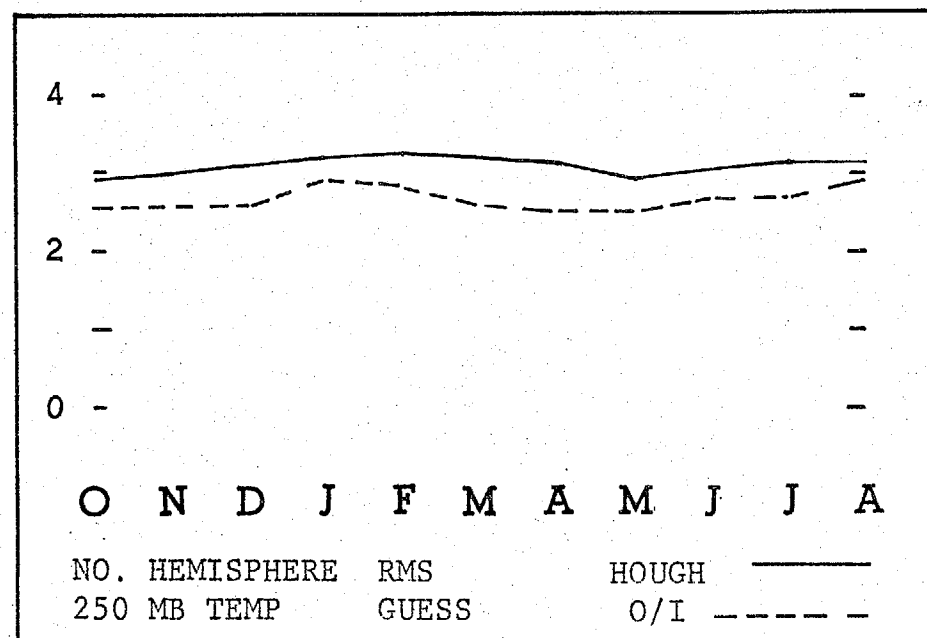
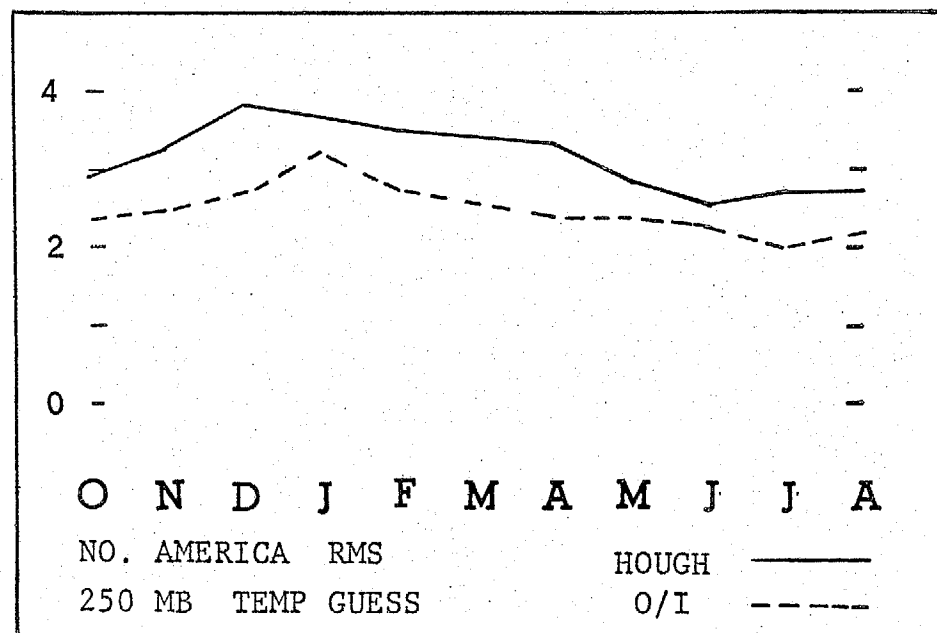
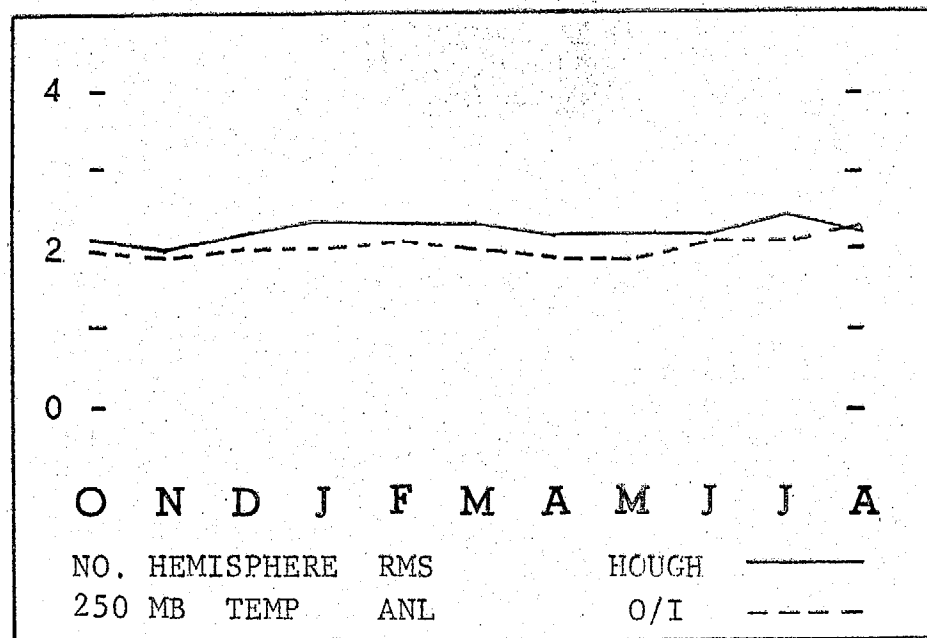
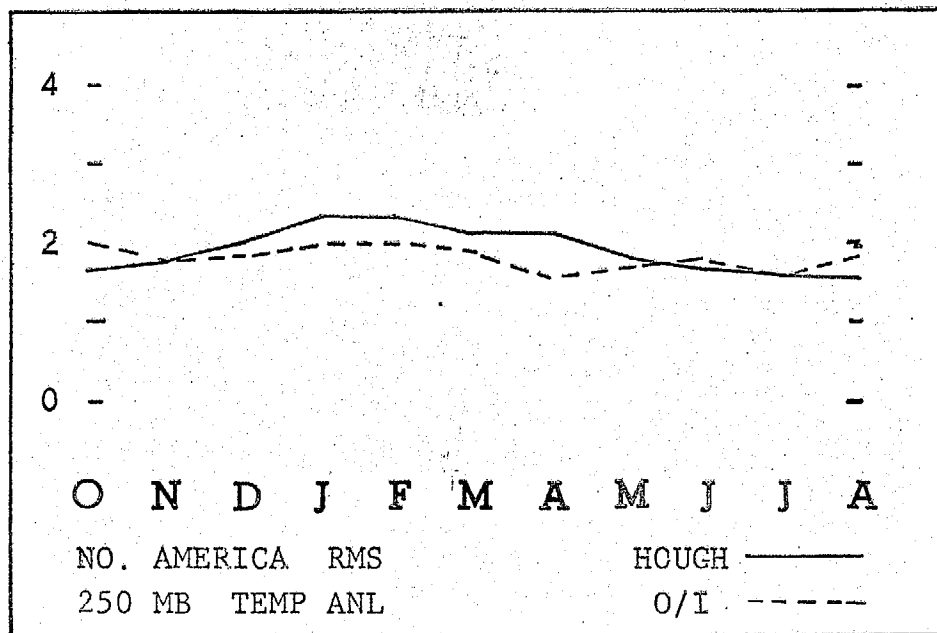


Fig 8c

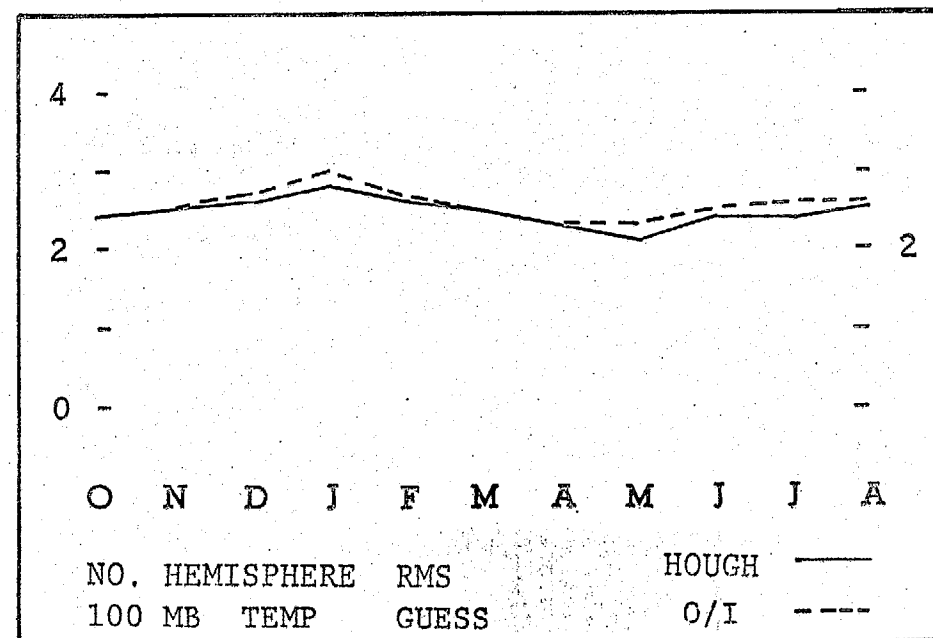
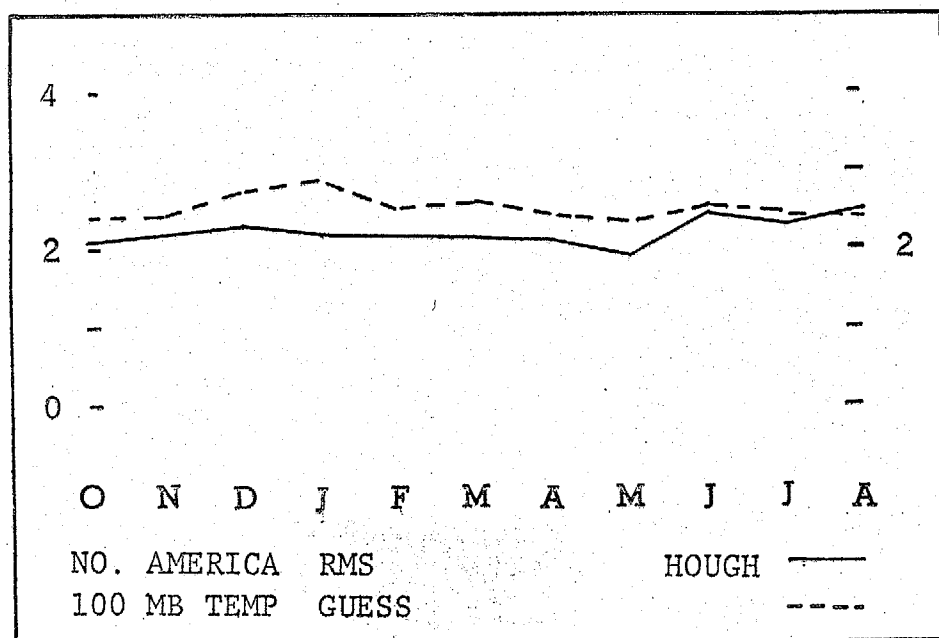
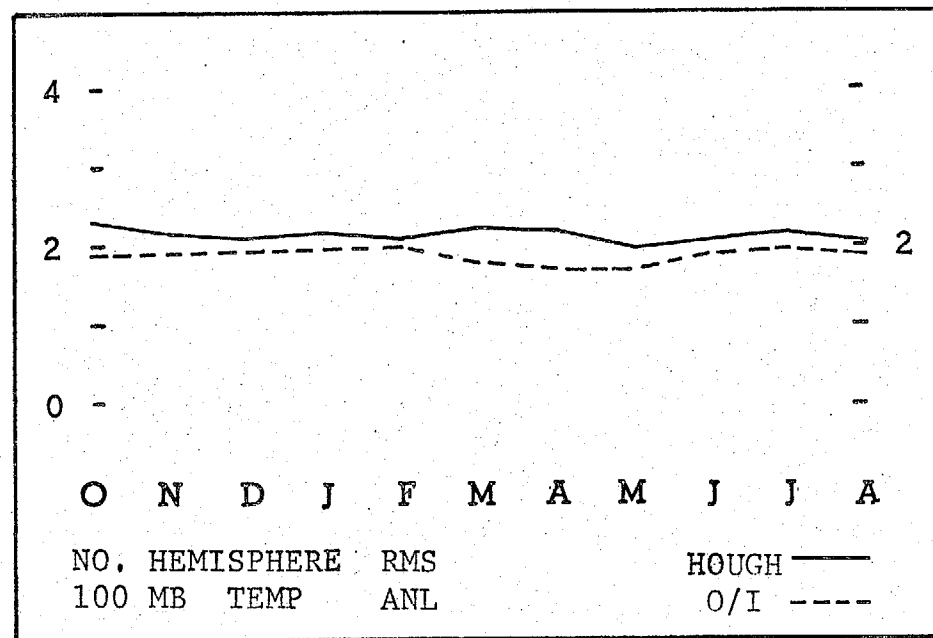
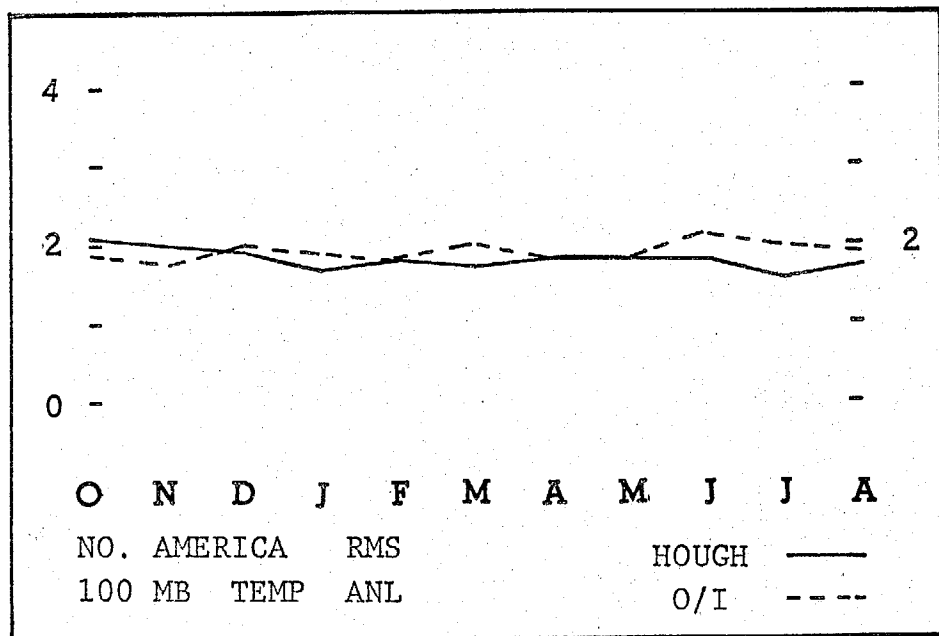


Fig 8d.